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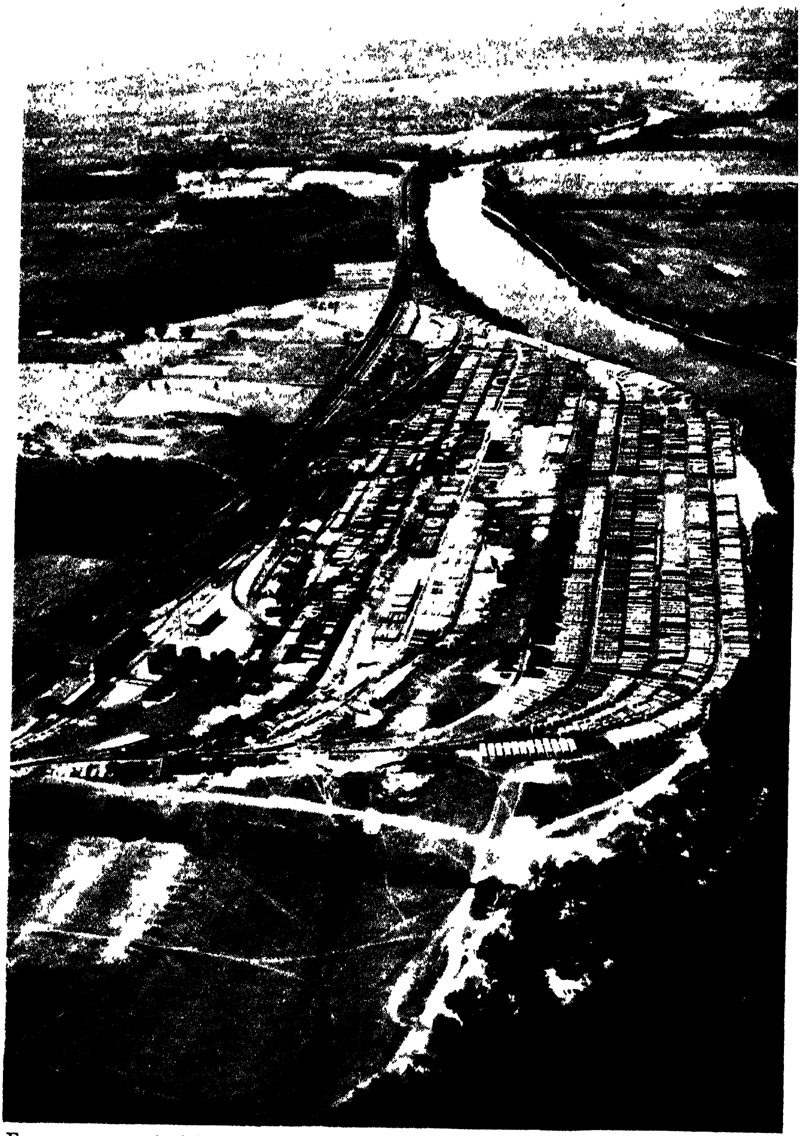
WOOD PRESERVATION



FRONTISPIECE.—Aerial view of a wood-preserving plant. (*The Wood Preserving Corp., Century Division, Nashua, N.H.*)

WOOD PRESERVATION

BY

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PREFACE

Although the modern wood-preserving industry has a definite place in our national economy, people in general are unaware of its existence. Even many of the producers and consumers of structural timber know little about the general principles involved in applying preservatives to wood and nothing as to the details. There has long been need for an up-to-date book, which would serve both as a text for students in schools of forestry and engineering and as a reference volume for those engaged in the wood-preserving industry, for purchasing agents and engineers concerned with the use of wood, and for executives pursued by purveyors of questionable preservatives and processes. Such a book might even help to enlighten inventors and other individuals who have deceived themselves into thinking that they have discovered new and revolutionary materials and methods.

There is an extensive literature on the subject of wood preservation, particularly in the publications of the U. S. Forest Products Laboratory, the American Wood-Preservers' Association, and the American Railway Engineering Association. A great deal of what has been published is highly technical, and much of it is controversial. No English book written during the past twenty years has seriously attempted to summarize the essential facts contained in this mass of information and to provide an easily accessible and orderly presentation of the fundamental principles. This is what the authors of the present volume have attempted to do, and it is their earnest hope that they have succeeded sufficiently well to meet the needs of students and others interested in becoming acquainted with the art of wood preservation. Anyone desiring to delve more deeply into the subject will find that the literature citations, while by no means complete, point the way to further profitable study.

In the preparation of this book, the authors have drawn freely upon all sources of information available to them. They have had the assistance of many wood-preserving plant operators and machinery manufacturers, who have been particularly helpful in furnishing illustrations. For their patience in reviewing many pages of manuscript and their invaluable aid in pointing the way to improvements in the text, especial acknowledgment is due the following members of the staffs of the U. S. Forest Products Laboratory and the Yale School of Forestry: R. H. Baechler, E. Bateman, J. D. MacLean, L. J. Markwardt, C. Audrey Richards (Bureau of Plant Industry), T. R. Truax, T. R. C. Wilson, and R. M. Wirka; and Professors J. S. Boyce, R. C. Bryant, R. B. Friend, and S. J. Record. A considerable amount of the material in this book is based on the work and publications of these cooperators.

GEORGE M. HUNT.
GEORGE A. GARRATT.

MADISON, WIS.,
December, 1937.

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WOOD PRESERVATION

CHAPTER I

THE FIELD OF WOOD PRESERVATION

WOOD AS A CONSTRUCTION MATERIAL

In the United States, as in other countries possessed of abundant timber resources, wood has always been a preeminent construction material. Its low cost and availability in various forms and sizes, together with such properties as relatively great strength with respect to weight, ease of shaping and fastening, low heat conductivity, and sound-deadening qualities, have made it the outstanding building material from the time of the first settlers down to the present. These and other advantages inherent in wood have also made it invaluable in the industrial development of the country. Even today, despite the extensive use of other structural materials, the railroads, telephone, telegraph, electric light and power companies, and the agricultural, mining, and navigation industries still depend upon wood to fill much of their construction requirements.

WOOD VERSUS OTHER STRUCTURAL MATERIALS

Not so many years ago wood was considered a virtual necessity in practically all forms of construction, but certain fundamental changes that have taken place in the United States during the past half century have brought it increasing competition from masonry, steel, cement, and allied products. As a result, the expansion in the use of wood has not kept pace with industrial development and increase in population, and both the production of timber products and their per capita consumption have shown a general decline during the past 30 years. In a large measure, the more or less extensive replacement of wood by other materials of construction, which has been especially marked in the building industry and certain other fields, has been the natural outcome of progress and invention, intensified by changing social conditions. But a more immediate cause is to be found in the real or assumed superiority of other materials under certain conditions of use. (10.*)

One of the significant features of the present-day building industry, at least in the more densely populated sections of the country, is the rather widespread replacement of frame structures with forms of construction involving the use of brick, stone, concrete, or steel. This change is especially evident in the larger cities, where the intensive use of space and the anticipation of permanence have led to the development of highly specialized types of buildings in which wood can be used only in part. In large communities, the detached wooden dwelling is being superseded by the multifamily residential unit, usually of masonry-wall or entirely fire-resistant construction; and the old wooden business block by the modern steel-framed, "fireproof" office building. Furthermore, because of the emphasis placed on fire resistance in theaters, hospitals, and other public buildings, all but minor items of woodwork are usually banned in such structures. In other fields, new types of construction, for which timber is generally unfitted, have also been evolved. Thus, concrete is the accepted material for the fabrication of large dams, retaining walls, and canals, while steel alone is suitable for the framework of very large bridges and big ships.

But, despite the marked extension in the use of competitive products, wood is still the leading structural material in many fields and will doubtless continue to maintain its preeminent position so long as an adequate supply is available at a cost within reason. No satisfactory substitute has yet been found for the wooden crosstie; while for such uses as posts, piles, poles, crossarms, mine props, car framing, bridges and trestles, and tanks, timber has repeatedly demonstrated its serviceability and economy in competition with steel and concrete and other materials. In the building field, the inherent advantages of wood have led to its continued and extensive use, not only in dwellings but in factories and other industrial buildings, in which the slow-burning, heavy-timber type of construction (formerly known as *mill construction*) is recognized as being not only economical in first cost and maintenance but also adequately fire resistive and otherwise serviceable. Furthermore, for products such as water (stave) pipe, conduit, and bridge and factory flooring, for which the use of wood had been almost abandoned, it is now becoming more and more favorably regarded as a construction material. It is also significant that, in some cases, the very displacement of wood has definitely enlarged the scope of its use. Thus, a great deal of lumber and dimension stock is frequently required for temporary purposes (forms and scaffolding) during the erection of tall buildings and other large structures made of concrete, steel, and brick.

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* Numbers in parentheses refer to the bibliographic items listed at the end of each chapter.

It may also be pointed out that, unlike the competing structural materials, timber is a renewable resource. Many wood products, and especially those that are used in small and moderate sizes, are obtained from trees that can be grown within a reasonable period of time and fairly close to most points of consumption. This is notably the case with such items as crossties, mine timbers, and fence posts, although even the larger products, such as poles and piles, may be successfully produced on relatively short rotations in regions where growing conditions are particularly favorable.

NEED FOR ECONOMY IN WOOD USE

Modern industrial developments have set up increasingly exacting service requirements for many timber products, with the result that the burden of supplying the demands of the consumers has become more and more concentrated on special kinds and grades of wood. Such factors as strength and durability have become of paramount importance in the general construction field, and the number of woods that are considered adequately suited for certain uses is definitely limited. It was inevitable that this intensified demand for a relatively small group of available woods should result in a constantly decreasing supply of acceptable material as well as in rising costs. Also contributing to the increased cost is the notorious waste that so often characterizes the manufacture and use of timber. Today a crosstie, bridge timber, telephone pole, or mine prop costs several times as much as it did 25 years ago. Part of this increase in price may naturally be attributed to advances in labor and other production costs, but there is no question that depletion in local supplies of some of the favored structural woods has had a decided influence. Consequently, more and more emphasis is now being placed on the need for greater efficiency in wood use.

The various organizations and individuals interested in furthering the use of forest products have done much in recent years to increase the serviceability of wood and the resultant economy in its utilization. Marked improvements have been made in manufacturing methods, seasoning, and other preparation of products for use, and these have not only raised the quality and added to the usefulness of the woods already regarded with favor but have also brought about the acceptance of some of the species previously considered as inferior. There have been decided advances in the grading of lumber and structural timbers; precise data have been derived on the strength properties of the various woods; and notable progress has been made in structural design. And, finally, definite strides have been made in the dissemination of knowledge concerning the proper selection and use of specific kinds and grades of wood. Many problems still remain to be solved in practically all fields of wood use before the consumer can be assured of obtaining the maximum service and economy out of the timber he purchases, and before the producer can meet the competition of other materials to best advantage. High efficiency can be obtained by the application of present knowledge, however, and continuing research promises improvement in the future.

THE BENEFITS OF WOOD PRESERVATION

Outstanding among the practices that have been developed to improve the serviceability of wood is the chemical (preservative) treatment of structural timbers and various other wood products used in construction under conditions that favor their early deterioration by decay, insects, and certain other destructive agencies. It is with the various aspects of this treatment that the subject of wood preservation is concerned.

The primary objective of the preservative treatment of wood is to increase the life of the material in service, thus decreasing the ultimate cost of the product and avoiding the need of frequent replacements in permanent and semipermanent construction. The outstanding examples of increased permanence through such treatment are afforded by the products that are exposed to the most severe attacks of wood-destroying agencies. Thus, in certain harbors along the south Atlantic and Gulf coasts, untreated piling may be destroyed by marine borers in a year or even less, while the estimated average life of thoroughly creosoted timber in such locations is conservatively placed at from 10 to 12 years, although there are numerous examples of much longer service. Likewise, in the underground workings of mines, in which temperature and moisture conditions are especially favorable for the development of decay, the average life of untreated wood may be only about 2 years, whereas creosoted props and other timbers have retained their serviceability for 20 years and more. Crossties, which have always made up the bulk of the material treated in this country each year, also clearly demonstrate the benefits of preservative treatment in protecting wood against the combined effects of decay and mechanical wear. Based on the service records obtained from more than 9000 experimental ties of 20 different kinds of wood laid in the tracks of the Chicago, Burlington, and Quincy Railroad Company in 1909 and 1910, the actual average life of the untreated crossties has been determined to be 5.5 years, while for those treated with zinc chloride (½ lb. per cubic foot of wood) and coal-tar creosote (10 to 12 lb. per cubic foot) the average periods of service are estimated at approximately 15 to 20 and 27 to 27.5 years, respectively (3). With the increasing appreciation of the efficacy of preservative treatment in prolonging the life of timber in exposed situations, treated wood has come to be regarded as one of the more permanent construction materials. Consequently, it is now better able to compete with steel and concrete in many forms of construction, especially as long-time use of these other materials has revealed their shortcomings and the expense often connected with their proper maintenance.

Experience has repeatedly demonstrated that the prolonged service life obtained with adequately treated crossties, poles, bridge timbers, and other forms of wood used in exposed situations in permanent and semipermanent construction almost invariably results in a distinct financial saving to the consumers of these products, despite the fact that the treated material may be definitely higher in first cost than acceptable untreated stock. In certain types of construction, as in some rural telephone lines, the charges for preserving the timber may so decidedly increase the cost of the completed installation as to be warranted only if the life of the wood is considerably in excess of that of untreated material. However, in bridges, wharves, and in fact most timber structures, the cost of preservation constitutes only a relatively small proportion of the total investment, and a slight to moderate increase in the serviceableness of the wood will more than justify the added expense. This is notably the case in buildings and other forms of construction in which only a small amount of the wood used needs to be treated to safeguard the structures from early deterioration by decay, insects, or other agencies of destruction.

The economy resulting from the use of treated wood in any form of timber construction is effected primarily through the reduction in the cost of maintenance. With some products, such as farmers' fence posts, the labor and other charges incidental to making frequent renewals may not be significant; but with others, as bridge timbers and poles in city distribution lines, these replacement costs are extremely important. As a specific example, one of the larger telephone companies operating in the Northeast places an average valuation of $37 on 35-ft. treated poles set in line; of this amount, only $12.50 is charged to the cost of the timber delivered in the distributing yard, and the greatest single expenditure is for the erection of the pole. In addition to the direct charges for labor and materials, replacements in electric light and power lines, street-railway tracks, and other structures may also entail inconvenient and expensive interruptions in service.

Because of the extent to which the railroads have adopted treated ties in recent years (page 15), these common carriers afford an outstanding example of the benefits to be derived from the widespread use of such material. Since 1915, there has been a fairly steady decrease in crosstie-maintenance requirements, as indicated by the records of the leading railroad systems in the United States (1, 8). In contrast to the 1915 average of 265 ties replaced per mile of track by the reporting railroads, the 1929 maintenance requirements amounted to but 176 ties. Since the latter year, the annual renewals have been drastically curtailed, reaching an all-time low of 73 ties per mile in 1933 for the roads under consideration. (See Table XVIII, page 288.)

While this notable decrease in renewals since 1929 is largely a reflection of the sharp reduction in the purchasing power of the railroads during the depression, it represents a tremendous saving in annual maintenance expenditures which was made possible only through the extensive use of treated ties during the preceding decade.

In the case of certain structural timbers, such as poles and the foundation supports of bridges and trestles, which are set in the ground and required to support definite loads throughout their service life, preservative treatment may have a special economic benefit. When used untreated, these forms of wood are subject to early and progressive deterioration by decay at the ground line, with an accompanying decrease in strength, so that it is general practice to specify timbers considerably larger than are necessary to carry the imposed loads at the outset of the period of service. The excess wood thus provided permits a certain amount of deterioration before replacement is necessary; the period of time that will ensue before the strength of the timber is seriously impaired can often be rather definitely forecast, as the result of past experience with the product and the kind of wood concerned. On the other hand, when adequately treated wood is used, the initial strength of the piece is maintained for a considerable period of time, if not for the duration of the structure, and there is, accordingly, no need to use decidedly oversized timbers. In certain less exacting uses of structural timbers, savings may often be made by the utilization of relatively low-grade material, which, when properly treated, will be at least fully as serviceable as better grade, untreated stock. Furthermore, because of the ease with which it can be impregnated with preservatives, sapwood is preferable to heartwood in material that is to be treated; hence, a closer utilization of timber is possible than when heartwood alone is specified for durability.

The protraction of the service life of timber by the application of suitable preservatives has had another very significant effect in the field of wood utilization, in that it has made available for use a rather large number of species which previously had been considered inferior solely, or primarily, because they lacked durability and gave only a short period of service when exposed to decay or to insect attack. For example, untreated red oak is mechanically as well suited for crosstie use as white oak, but red oak ties become so badly decayed after about 5 years in track that it is necessary to replace them; heart white oak ties, under similar conditions of use, may have an average life of 11 years (3) and have naturally been preferred, even though their initial cost may have been considerably higher. When adequately treated with creosote, however, red oak ties will last fully twice as long as those of untreated heart white oak and are decidedly more economical to use.

Red oak is but one of a considerable number of woods whose utility has been definitely increased through preservative treatment. Others, including the gums, maples, birches, beech, southern pine, ponderosa pine, and lodgepole pine, are also coming into much more extensive use, not only for crossties, but for posts, poles, mine timbers, and other products that are subject to more or less rapid deterioration in service. Furthermore, it is now recognized that the benefits of treatment may be extended even to the highly durable woods. Thus, the life of the naturally decay-resistant white oak crosstie may be practically doubled when adequately impregnated with creosote (3), while the service period of chestnut and cedar poles may be increased by at least 5 to 15 years by the nonpressure butt treatments that are given these woods (4).

The adaptability to preservative treatment of woods that are naturally nondurable, but otherwise acceptable to the industries, has not only increased the supply of timber available for construction purposes but has also brought about certain other benefits to both producers and consumers of forest products. Inasmuch as the timberland owner and operator is often able to find a market for woods that are otherwise difficult, if not impossible, to dispose of, he may be able to improve definitely the composition of his stand by the gradual elimination of certain of the "inferior" species, thus favoring the growth of woods that are more valuable for lumber, pulpwood, or other products. Under favorable circumstances, he may even find a profitable outlet for the smaller material removed in thinnings and other improvement cuttings. The consumer, in his turn, is offered a more diversified group of woods from which to make his selection, with the resultant competition between species at times effecting a reduction in purchase price. In such products as crossties, mine timbers, and posts, the woods grown locally are often favored on a cost basis, since they do not have to carry the high transportation charges imposed upon products shipped from other regions.

DEVELOPMENT OF THE WOOD-PRESERVING INDUSTRY

In the following brief statement of the development of wood preservation, discussion of the very early history of the subject has been purposely omitted. Wood preservation began in earnest during the second quarter of the nineteenth century, with the patents of Kyan, Burnett, and Bethell, and what was done prior to that time is of little moment. Furthermore, because of space limitations and the fact that the descriptive material incorporated in the ensuing chapters is based primarily on American practices, this account is almost entirely restricted to the development of the industry in the United States. For more extensive information on the subject the reader is referred to other publications. (2, 5, 12.)

Early Development in Europe

Mercuric chloride (corrosive sublimate) was used by Homberg for protecting wood against the ravages of decay as early as 1705 and by De Boissieu in 1767. In the latter year, both De Boissieu and Bordenave recommended the use of copper sulphate (blue vitriol), but it was some time before these two chemicals gained definite recognition as wood preservatives. It was not until 1832 that Kyan obtained a patent for the treatment of wood with the former salt, while Margary's patent for the use of the latter was not issued until 1837; treatments involving immersion in solutions of mercuric chloride are still frequently referred to as *Kyanizing*. A somewhat different type of treatment with copper sulphate, as well as certain other chemicals, was patented by Boucherie in 1839. This Boucherie process is unique in that it is designed for the treatment of living trees and of unseasoned and unpeeled timber and is not effective with seasoned wood.

Zinc chloride was recommended as a wood preservative in 1815 by Thomas Wade and again in 1837 by Boucherie, but the first patent covering the use of this salt was issued to Sir William Burnett in 1838. The original Burnettizing method provided for the immersion of wood in solutions of zinc chloride in open tanks; but in 1847, a pressure process was devised which was the forerunner of the modern Burnett treatment.

The use of coal-tar creosote was first patented in 1836 by Franz Moll, but the recommended method of treatment was impracticable, and little, if any, use was made of it. Two years later, John Bethell was granted a patent for injecting creosote into wood under considerable pressure. Although this patent was concerned with the method of treatment rather than the kind of preservative used, the modern Bethell, or so-called *full-cell*, process makes exclusive use of creosote and certain creosote mixtures. This distinct departure from the nonpressure steeping processes, in vogue prior to 1838, met with outstanding success and has served as the basis for most of the present-day methods of wood preservation.

DEVELOPMENT OF THE INDUSTRY IN THE UNITED STATES

One of the earliest, if not the very first, wood-preserving patents recorded in the United States was granted by the Province of South Carolina to Dr. William Crook in 1716. (See Appendix.) This covered a preservative, "One Part of which is the Oyle or Spirit of Tarr," which was advocated for the protection of ship planking against shipworms and decay. Nothing more definite is known about the composition of the preservative, nor is there any record that the compound was ever made or sold. The first colonial concession for treating wood was granted in 1737, and, following that, a number of attempts were made to introduce wood preservation into this country. However, it was not until the middle of the nineteenth century that the treatment of timber became of practical importance in the United States.

Water-soluble Salt Treatments.—In 1848, the first commercial plant was built at Lowell, Mass., mainly for the purpose of Kyanizing timbers to be used in locks and canals on the Merrimac River. Kyanized crossties and other products were used for a few years by several of the Eastern railroads, but during the second half of the nineteenth century, and especially after 1885, major attention was directed to the pressure treatment of wood with zinc chloride. During this period a number of Burnettizing plants for treating ties and other timbers required by the railroads were constructed in various sections of the country. In more recent times, the wood-preserving field has been largely dominated by the various creosoting treatments, but the use of zinc chloride is still a significant factor in the industry, and the Burnett process is recognized today as one of the few standard methods of impregnating timber.

As the use of zinc-treated material became more extensive, it was found that the water-soluble salt was rather readily leached out of wood placed in exposed situations, especially in more or less humid climates. In order to increase the efficiency of the treatment, several pressure processes were developed for impregnating timber with zinc chloride and some other substance which would tend to retard the leaching action. Thus, in 1879, Wellhouse and Hagen introduced a process providing for the treatment of wood, first with a combination of zinc chloride and glue and then with tannic acid; upon combining, the glue and tannin form a leathery precipitate which was believed to seal in the zinc chloride. Several railroads are reported to have installed ties treated in this way, but the process probably has not been used in the United States for at least 25 years. The Allardyce process, providing for an initial impregnation with zinc chloride and a subsequent treatment with creosote, was introduced shortly after that of Wellhouse but was apparently used only during the late 90's. In 1906, J. B. Card patented a method involving a one-movement impregnation with a mixture of zinc chloride and creosote,* thus providing a treatment that is intermediate in both permanence and initial cost to those obtained by the Burnett and the Bethell processes. The Card method was accepted as a standard treatment for crossties and certain other classes of material and used almost exclusively for a number of years by several important railroads. Following the peak years of 1922–1927, however, there was a marked decline in the use of zinc-creosote-treated material, and in 1934 the process was abandoned.

Creosote Treatments.—The pressure treatment of wood with creosote began to assume a position of major importance in the United States during the latter part of the nineteenth century.

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* A similar treatment had been invented in Germany in 1874 by Julius Rütgers, but there is no evidence that it was ever used in the United States. The Card process differs from that of Rütgers essentially in the manner of keeping the zinc chloride and creosote mixed.

The first Bethell-process plant (Fig. 1) was erected in 1865 at Somerset, Mass., for treating railway material; but much more significance is attached to the installation of treating equipment at West Pascagoula, Miss., in 1875. The establishment of the latter plant, which was built by the Louisville and Nashville Railroad for the treatment of piles, stringers, caps, and ties, is generally considered to have initiated the modern timber-preserving era. The marked development in treating equipment since 1865 is indicated by the modern plant shown in Fig. 2. During the earlier stages of the subsequent development of creosoting treatments, the Bethell process was used almost exclusively, although certain modifications of it were devised in order to make possible the satisfactory treatment of unseasoned timber. To this end, the Boulton, or boiling-under-vacuum, process was patented in the United States in 1881, and the boiling method in 1895.

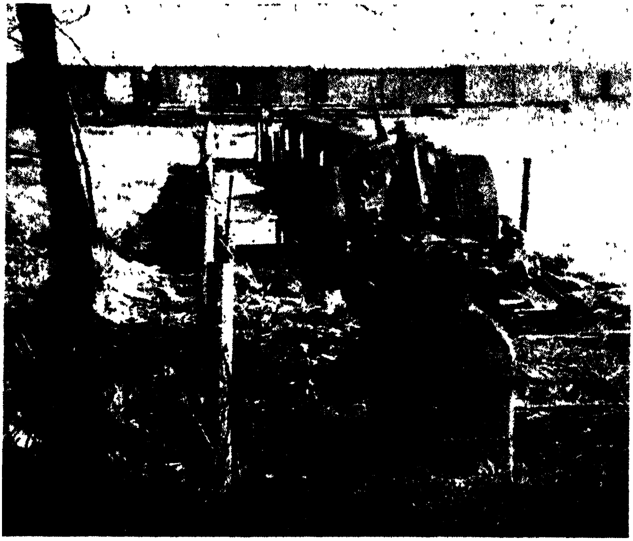

FIG. 1.—The first Bethell-process plant in the United States. This plant was constructed in 1865 by the Dighton and Somerset Railroad, at Somerset, Mass. (*N.Y., N.H. & H.R.R.*)

The pressure creosote treatments were generally successful from their inception, both in this country and abroad, but the high cost of the oil stimulated interest in methods of reducing their expense. To economize on the amount of preservative used, Max Rueping devised the so-called *empty-cell* process which bears his name, obtaining a patent in 1902. A second empty-cell treatment was patented by C. B. Lowry in 1906. Both the Rueping and the Lowry processes provide for the impregnation of wood with a relatively large amount of creosote and the subsequent withdrawal of part of the oil, giving a smaller final retention of preservative than is usually obtained in the Bethell process. They are used extensively in the United States for the treatment of crossties and other products, in which relatively deep penetrations but only moderate absorptions are desired.

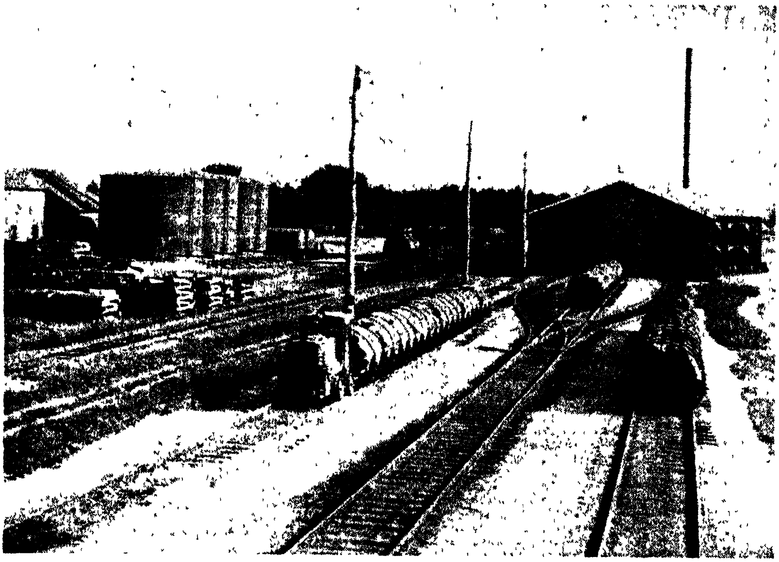

FIG. 2.—A modern two-cylinder wood-preserving plant. (*The Wood Preserving Corp., Century Division, Nashua, N.H.*)

The demand for economy in the use of creosote has also led to its mixture with such substances as coal tar, water-gas tar, and petroleum, especially for the treatment of crossties and switch ties. A canvass of railroads in the United States and Canada, made in 1927, showed that at that time most of the companies were using ties impregnated with these mixtures. Since the tars are relatively low in toxicity, and the petroleums entirely lacking in this property, they have no outstanding preservative value. However, these diluents materially reduce the cost of the preservative without destroying its efficiency and may also increase the resistance of the treated ties to checking and mechanical wear in service. Coal tar was apparently used in mixture with creosote in the United States as early as 1908, while the first reported use of petroleum for such a purpose was in 1909.

One other method of creosoting timber should be mentioned in this discussion, *viz.*, the hot and cold bath for treating material without the use of artificial pressure. The general features of this process were originally patented in 1867 by Seeley, and a number of treating plants were built in that year for handling government and railroad work. The results were not satisfactory, however, and nothing further was done with the process in this country until 1904, when Von Schrenk revived it. Since that time it has been rather widely used for the treatment of poles, posts, and certain other products.

Classes of Material Treated.—The real advance in wood preservation in the United States, as well as in most other countries, came with the development of the railroads. In fact, it was chiefly through the demands of the railroad companies for treated timber that the industry was built up to a position of major importance and subsequently maintained. Since 1909, when the compilation of definite statistics was first undertaken by the U. S. Forest Service in cooperation with the American Wood-Preservers' Association, crossties have constituted the bulk of the wood treated annually in the United States (6). In that first year, they made up approximately 82 per cent of the total material treated, as was also the case in 1921. Since the latter year, however, the proportion has declined rather steadily, especially as treatment has been applied more extensively to other forms of structural timber. In 1929, the peak year for the output of treated wood, crossties made up about 59 per cent of all the material given preservative treatment; this figure was increased to 67 per cent in 1932; but in 1934, it reached a new low of slightly more than 50 per cent. The railroads have also used large quantities of other treated products, such as switch ties, bridge, trestle, and other construction timbers, crossing plank, car material, and tie plugs.

Direct evidence of the continually increasing appreciation of the benefits to be derived from the treatment of crossties is afforded by the statistics on the use of such material by the railroads. Prior to 1885, preservatives were applied chiefly to piles and to dock and bridge timbers, and practically all ties were placed in track untreated. Since that time, however, the ratio of treated to untreated ties used annually has increased very rapidly. In 1900, about 3.3 per cent of all the ties used by the the railroads were treated; by 1910, the percentage had increased to 20.6; in 1920, it had jumped to 43.5; and in 1930, it reached a high mark of 78.5 (9). During recent years, the majority of the leading railroads in the United States have used few, if any, untreated crossties, and many of these report that treated ties now constitute 90 per cent or more of the total ties in track (1, 8).

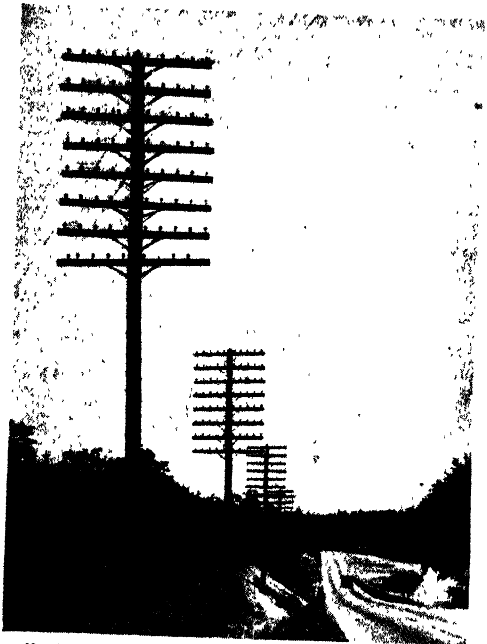

FIG. 3.—An installation of creosoted poles along a modern highway. The eight crossarms carry a total of 78 wires.

The successful use of treated ties and other wood products by the railroads has done much to stimulate the interest of other large industries in the preservation of their structural timbers. Telegraph, telephone, electric light, and power companies are now making wide use of treated poles and crossarms (Fig. 3)

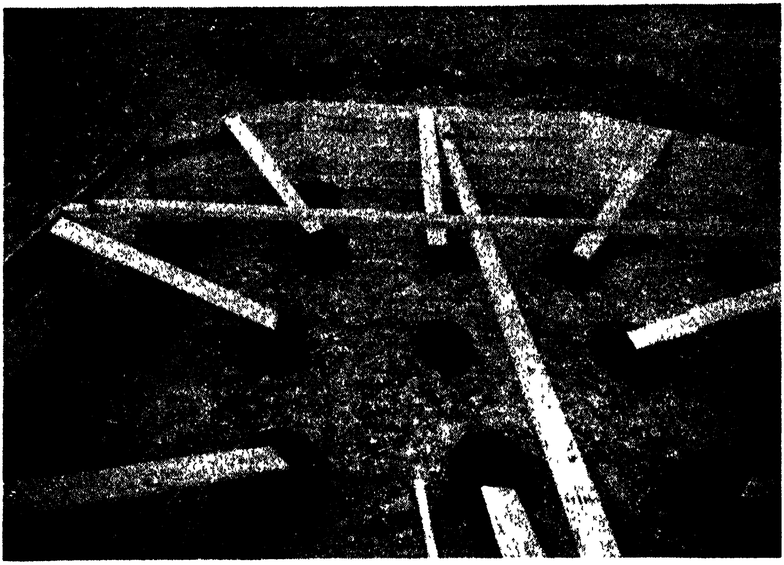

FIG. 4.—A few of the creosoted foundation piles used for supporting the new Union Station at Cincinnati, Ohio.

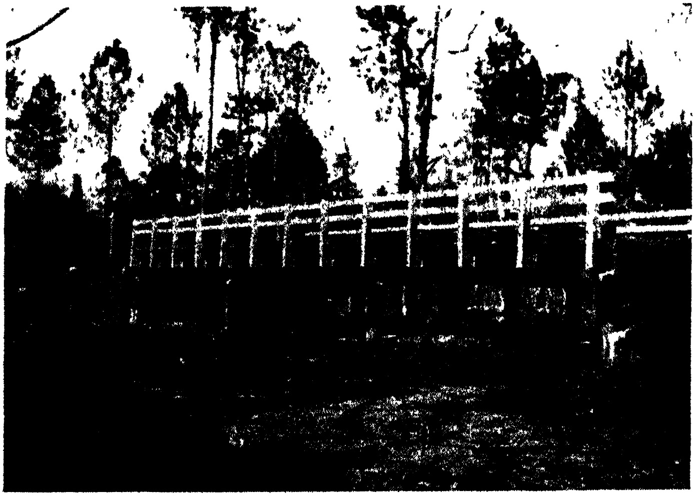

FIG. 5.—A pressure-creosoted bridge on a secondary highway. Guard rails treated with a water-borne preservative would prove more economical than the untreated ones which were used in this structure to permit painting. Low-cost permanent bridges of this type are especially suitable where limited funds are available for road construction and maintenance.

as well as a certain amount of creosoted conduit for underground work; dock, terminal, and construction companies and steamship lines are turning more and more to creosoted piling (Fig. 4) and to other needed products furnished by the wood-preserving industry; many mining companies are now definitely committed to the use of treated ties, props, and other timbers; national and state highway organizations are making increased purchases of treated fencing, guard rails, and bridge timbers (Fig. 5); and public works of various kinds are affording added outlets for construction timbers that have been impregnated with preservatives. The extent to which the principal types of wood-construction products have been subjected to preservative treatment in the United States is indicated in Table I. Added statistical data, pertaining to the volume of materials treated, are to be found in the Appendix.

TABLE I.—AMOUNTS OF PRINCIPAL WOOD PRODUCTS TREATED IN THE UNITED STATES

(By odd years, 1909–1935)

Year	Number of crossties	Switch ties, feet b.m.	Piles, linear feet	Number of poles	Wood blocks,* square yards	Number of crossarms	Construction timbers,† feet b.m.	Lumber, feet b.m.
1909	20,693,012	.	6,538,113	37,481	1,140,682	67,383	63,433,440	
1911	28,394,140	.	7,300,552	6,035	3,865,038	116,104	101,531,472	
1913	40,260,416	.	11,766,852	142,069	2,611,616	2,944,045	139,843,536	
1915	37,085,585	. . . ..	9,308,419	142,772	2,936,370	146,219	142,009,041	
1917	33,459,470	. .	12,695,567	382,044	3,461,040	413,097	137,940,912	
1919	37,567,927	....	13,557,519	378,481	1,795,687	121,507	144,742,477	
1921	55,383,515	... .	8,268,519	622,685	2,363,011	175,403	142,520,494	
1923	53,610,175	. . . .	14,149,701	1,527,665	1,878,974	677,970	226,053,542	8,231,959
1925	62,563,911	163,401,124	14,249,220	2,397,978	1,298,472	1,003,073	172,508,302	14,692,392
1927	74,231,840	182,411,211	17,241,345	3,637,989	2,008,160	1,626,641	208,128,736	58,408,234
1929	71,023,103	173,107,698	25,324,255	4,383,768	2,610,335	3,158,165	242,445,744	87,972,030
1931	48,611,164	130,770,378	17,920,864	2,270,799	478,692	515,690	199,488,860	43,119,020
1933	22,696,565	65,163,336	9,172,871	1,711,411	148,014	505,712	145,881,023	22,200,171
1935	34,503,147	94,037,859	12,678,607	2,033,700	565,261	567,080	188,199,668	49,705,675

* Includes both inside flooring and outside paving.

† Includes timbers, other than piling, for use in construction of highway and railroad bridges, trestles, docks, wharves, and public works.

Volume of Material Treated.—A definite gauge of the development of the wood-preserving industry, in response to the stimulus of increasing industrial demands, is furnished by the following statistics on number of plants in operation and volume of wood treated in the United States:

Year	Number of plants in operation	Volume of wood treated, millions of cubic feet
1904	33	21
1909	64	76
1914	94	160
1919	108	146
1924	162	269
1929	203	362
1933	187	126
1936	200	222

During the 28-year period from 1909 to 1936, inclusive, the output of the treating plants in the United States aggregated over 5½ billion cubic feet of timber. In the peak year of 1929, the equivalent of 4,344,108,000 ft. b. m. of wood was treated; approximately 226 million gallons of creosote, 30 million gallons of petroleum, and 20 million pounds of zinc chloride were used in preparing almost 99 per cent of this volume of timber for service, the balance being treated by various miscellaneous chemicals, including a number of proprietary preservatives. Ninety per cent of the total volume of wood treated was impregnated by pressure processes, the remainder being prepared by the hot-and-cold-bath process. From 1929 to 1933, a marked and generally consistent decline occurred in the output of most classes of treated material (see Table I), reflecting the drastic curtailment in the purchasing power of practically all groups of consumers. The volume of wood treated in 1933 was practically the same as that turned out by the 84 plants in operation in 1912 and was lower than the output during all of the intervening years except 1918, when about 123 million cubic feet of wood were subjected to treatment. Since 1933, the trend has again been upward, although the annual output is still far short of the 1929 peak. In 1936, the equivalent of 2,669,568,000 ft. b. m. of wood was treated; 155 million gallons of creosote, 23 million gallons of petroleum, and 4 million pounds of zinc chloride were used, together with nearly a million pounds of miscellaneous salts and a few thousand gallons of various liquid preservatives.

The figures that are given do not include such wood as is treated in the field or in place or in "home" plants of small capacity, since it is impossible to obtain adequate statistics on this material. There is every reason to believe that a considerable amount of wood is treated in this way and that the volume will increase annually as the economy of even the superficial preservative methods becomes more fully appreciated.

Present Opportunities for Expansion.—While much has been accomplished by the railroads and most of the other large industries in obtaining maximum service from structural timbers and other forest products, a beginning has scarcely been made in developing the use of treated wood in certain other fields, especially those which immediately concern the consumers of small amounts of wood. Although more wood is probably used annually for agricultural purposes than in any other single industry, and much of it is subject to early deterioration by decay, the farming industry ranks very low as a purchaser of treated timber. Much the same situation exists in the small-building field. Even if the average farmer or homeowner desires to use a few hundred or thousand feet of treated wood, he is rarely able to purchase it. Few wood-preserving plants have either the equipment or the sales organization to handle small orders of mixed lumber, and the retail lumber trade has been largely apathetic to the possibilities of stocking standard treated products, such as small bridges and culverts for secondary roads or farm use; farm gates; silos; sills and other foundation timbers and flooring for stables, sheds, chicken and hog houses, and other farm buildings; outdoor steps and porch framing; joists and subflooring and other wood over unexcavated spaces; window frames and sash; and other miscellaneous items. Individually, such articles are relatively unimportant from the point of view of lumber consumption, but in the aggregate they constitute a large volume of sales and should afford a very desirable outlet for treated wood. (7, 11.)

The field has not been entirely neglected, however, and efforts have been made in a few sections to develop a retail trade through local lumber distributors, so that the small consumer can obtain, at reasonable cost, the material that he needs for repair or initial construction (Fig. 6). But greater efforts and diversification are required, and there is urgent need for an intensive study of merchandising problems in connection with the distribution of treated products to the farmer, the urban and suburban home-owner, and other purchasers of small quantities of wood.

Another form of wood treatment, which because of its character properly falls within the scope of the wood-preserving industry, is that of making wood fire resistant by chemical impregnation.

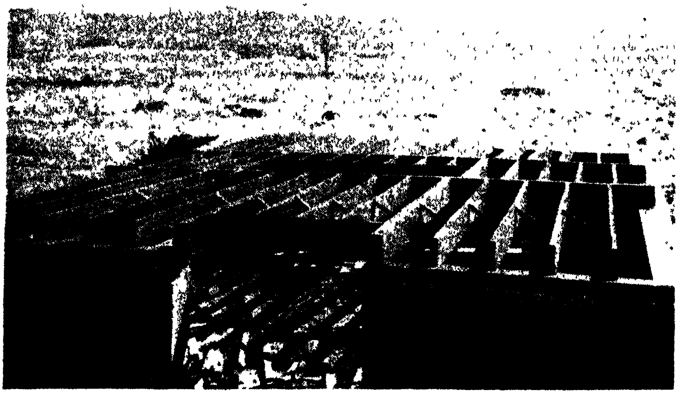

Fig. 6.—Creosoted sills and joists used in the construction of a dwelling.

So-called "fireproof" treatments of wood have been in commercial use in this country for 40 years (see Chap. XII), but, because of their recognized limitations, wood preservers, as a group, have given them little or no recognition. However, the more or less concentrated attack now being made on the problem of making wood fire retardant and the possibility of developing treatments that combine both fire and decay resistance in a practical way have stimulated renewed interest in the subject.

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CHAPTER II

AGENCIES OF WOOD DETERIORATION

Timber, in its various forms, is subject to several types of deterioration following its removal from the forest.* Wood-inhabiting fungi, especially those whose activities result in decay, destroy or depreciate enormous quantities of lumber and other forest products annually. Wood-boring insects, particularly termites, are responsible for extensive damage to wood in storage and in service. Fire exacts a heavy toll, especially in building construction, and marine borers are a constant and serious menace to piling and other forms of wood exposed in salt water. In addition, a large amount of timber is rendered unfit for further use through mechanical wear. Even weathering may bring about a definite disintegration of wood under certain conditions of exposure. Often two or more of these agencies may work in conjunction with one another. Thus, failure of certain products, such as crossties, is generally attributable to the combined effects of decay and mechanical wear, while various forms of wood are frequently subjected to deterioration through the concerted attacks of fungi and insects.

The deterioration of crossties, poles, posts, piles, mine timbers, and various other forms of wood used for construction purposes represents a loss of many millions of dollars annually. A large percentage of the destruction or depreciation of these products is unavoidable, especially in material in service, but much of it can be prevented, or at least reduced, by the intelligent selection, preparation, and use of wood for specific purposes. To this end, an understanding of the requirements for the inception and development, together with other significant characteristics, of the several causes of deterioration is essential. These features are discussed in the following paragraphs.

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* Certain of the agencies of deterioration under consideration, notably decay-producing fungi and wood-boring insects, cause heavy losses in standing timber and in felled material that is left in the woods for a protracted period of time. However, these aspects of the problem of wood utilization are beyond the scope of this text, which is primarily concerned with the destruction and depreciation of wood in service.

WOOD-INHABITING FUNGI

Wood is commonly invaded by certain low forms of plants, known as wood-inhabiting fungi. Because of the medium in which they develop and their saprophytic or parasitic nature, fungi are distinctly different from ordinary green plants in form and method of nutrition. Unlike green plants, they are unable to synthesize their own food but must have organic material already prepared for their use. This they find in the products stored in the cell cavities of the wood in which they are growing or in the actual wood substance composing the cell walls.

While there are many wood-inhabiting fungi, they vary widely in their precise effects. Three groups of these plants may be distinguished, depending upon the nature of their development in and on wood and the type of deterioration for which they are responsible. These are the wood-destroying fungi, the wood-staining fungi, and the molds. The first group is by far the most important, embracing those fungi that are capable of disintegrating the cell walls and thereby changing the physical and chemical properties of the wood; this disorganization of the material gives rise to the condition known as *decay* (also designated as rot, dote, doze, or punky wood). The staining fungi and molds, on the other hand, usually feed on the easily digested organic compounds stored in the wood and frequently have no appreciable effect on its properties; the former cause discolorations which may be classed as defects in lumber and certain other products, while the molds rarely discolor wood except superficially.

DECAY

Practically all wood is exposed, at one time or another, to attack by wood-destroying (decay-producing) fungi. Infection may take place while the wood is in the form of logs, bolts, or cordwood stored for hauling or manufacture; after it has been converted into lumber, crossties, or other forms and piled for seasoning or storage; or during the time that it is in service as a wood product.* Once decay has started in a given piece of wood, the rate and extent of the subsequent deterioration are dependent upon the maintenance of conditions that favor the growth of the causal fungus.

It is impossible to secure accurate data as to the amount of timber that is cut annually for the sole purpose of replacing wood rendered unfit for use by the activities of wood-destroying fungi. However, recent estimates made by the U. S. Forest Service, in connection with the preparation of the *Copeland Report* (11), indicate that the overcut necessary to replace decay losses in all classes of forest products amounts to more than 10 per cent of the total cut. Based on the average annual cut for the years 1925–1929, inclusive, this is equivalent to almost 1½ billion cubic feet of timber per year, or approximately one-fifth of the estimated current growth.† Losses in crossties, fence posts, poles, mine timbers, and other forms of wood placed in contact with the ground are exceptionally heavy, since the conditions under which they are used are particularly favorable for the development of decay. In lumber and structural timber, on the other hand, the proportion of material rendered unfit for further service is not high, but the amount so deteriorated constitutes an important part of the total decay loss because of the large volume of these products in actual use.

The monetary loss, due to the decay of wood in service, cannot be based solely on the purchase price of the replacement material, since the labor and other charges incidental to installation must also be considered. As has been previously indicated (page 6), these replacement charges vary widely in different types of construction and often aggregate decidedly more than the original cost of the timbers used. On the basis of production and prices for the years 1925–1929, the *Copeland Report* places the average annual cost of replacements, necessitated by decay, at over 250 million dollars, or more than half the yearly fire loss reported by the Board of Fire Underwriters for the same period. In arriving at this estimate, allowances were made not only for the labor costs of making replacements but also for the fact that losses occur at different stages between the felling of the timber in the woods and the use of the material in buildings, fence and pole lines, railroad tracks, etc.

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* Many living trees begin to decay on the stump, especially when they have reached maturity or have been weakened by insect attack, mechânical injury, or suppression (3, 16). While this discussion is not concerned with the activities of wood-destroying fungi in standing timber, it should be borne in mind that certain of these decays may continue to develop after the tree has been felled and cut into lumber or other wood products, unless the necessary precautionary measures are taken.

† According to the *Copeland Report*, the estimated overcut required for decay replacements in products derived from saw timber alone is approximately 9 per cent of the saw timber cut, or an average of almost 5 billion board feet annually, for the years 1925–1929. In some ways, this figure is more significant than that given above for all classes of forest products; not only does it pertain to material of greater unit value, but the rate of replacement by growth in the forest is relatively slow. The indicated overcut is equal to about half the estimated current growth for this class of material.

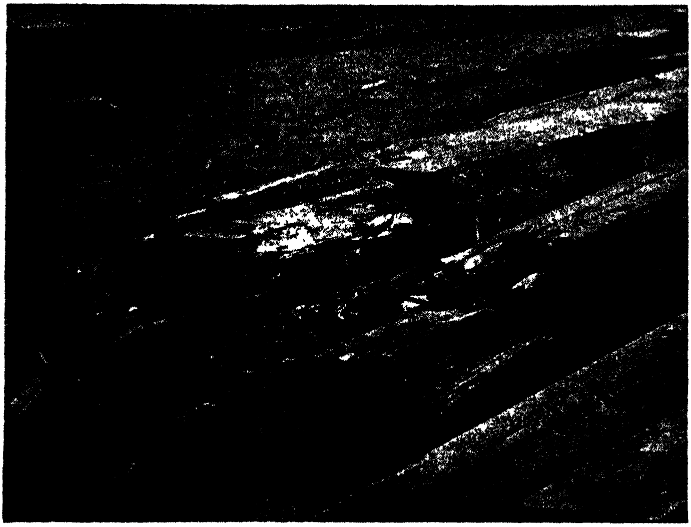

FIG. 7.—Decay at the ends caused the removal of these untreated timbers. (*U.S. Forest Products Laboratory.*)

A significant factor to be considered in viewing decay loss in certain structural uses of wood, where strength is an essential consideration, is that the deterioration of only a small portion of a timber may render the entire piece unfit for further use. Thus, the decay of a relatively small amount of wood at the foot of a bridge timber, at the ground line of a pole, or at the end of a wooden girder or beam may result in the whole stick

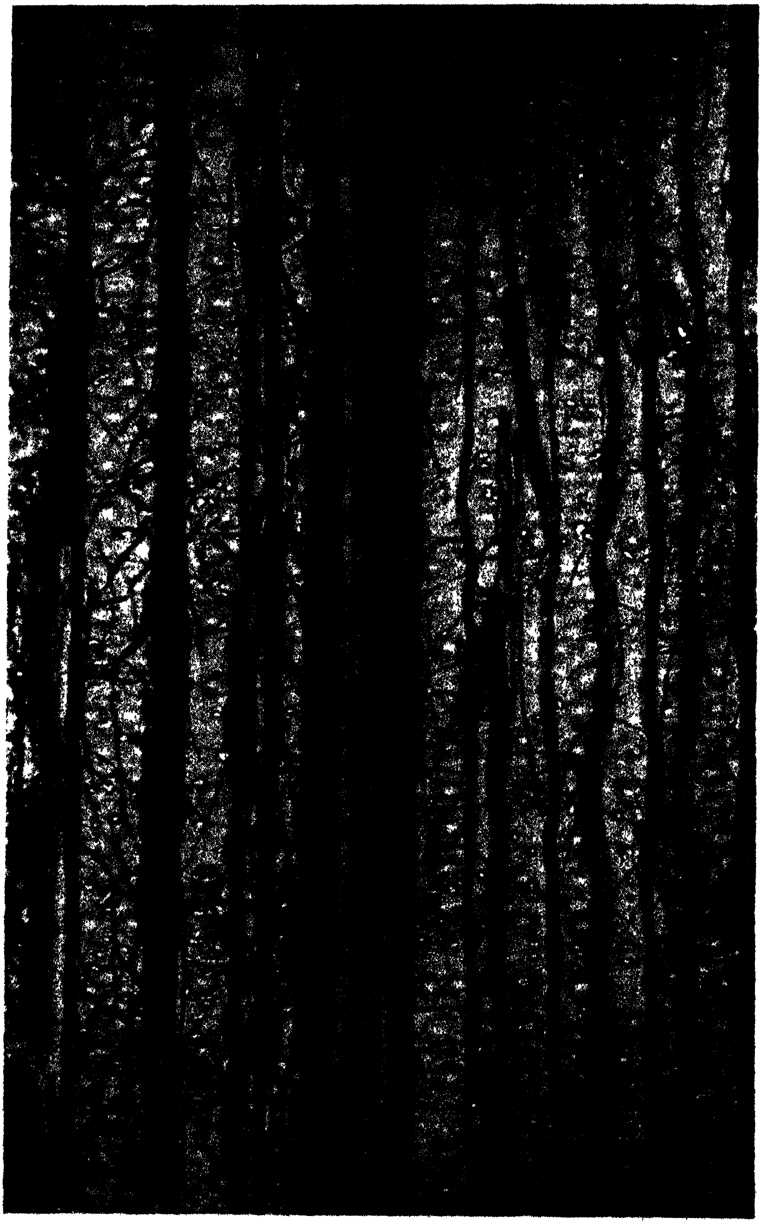

FIG. 8.—Photomicrograph showing hyphae of *Fomes pini* in southern pine wood. Note the numerous irregular "bore holes" in the cell walls. (*U.S. Forest Products Laboratory.*)

being reduced to the state of second-hand lumber or firewood or even entirely discarded (Fig. 7).

While much of the decay of wood in service is inevitable, it is recognized that the loss from this source can be greatly reduced. In fact, some authorities (8) have estimated the possible saving at almost half of the annual loss. Much can be accomplished by proper handling and storage of the material from the time that it is cut in the woods until it is put into use. Additional savings can be made, especially in the building field, by the design of structures to avoid unnecessary exposure of wood to conditions favorable to decay. And finally, in the manifold instances in which it is impossible or impracticable to prevent such exposure, the treatment of wood with suitable preservatives offers extensive possibilities in decreasing the loss. Much has already been done along the lines of decay prevention, especially in certain fields of wood use, but a great deal more remains to be accomplished.

The Cause of Decay.—Decay, in wood and other organic substances, was formerly considered to be due to some spontaneous process taking place within the affected material and entirely unrelated to the activities of fungi, bacteria, or other living agencies. During the middle of the nineteenth century, the generally accepted theory was that expounded by the German chemist Liebig, who held that decay of both animal and vegetable matter was caused by a slow combustion, to which he applied the term *eremacausis*. It was not until some years later that the true nature of the decay processes was established.

It is now almost universally recognized that the decay of wood is the result of the activities of low forms of plants known as wood-destroying fungi.* Following infection, the fungus develops within the wood, forming microscopic, threadlike structures, which are known individually as *hypha* (plural hyphae) and collectively as *mycelium* (Figs. 8 and 9). Under favorable conditions, the hyphae may also develop on the surface of the wood (Fig. 10) or in checks or other openings within it, as closely woven strands or rootlike masses or as feltlike (frequently fan-shaped) mycelial sheets, which are usually white or a shade of brown and readily visible to the naked eye. The mycelium constitutes the absorbing system of the fungus, being somewhat

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* Cellulose-dissolving bacteria are not considered to play an important part in the decay of wood under natural conditions, although the rate of decay may be increased by the presence of saprophytic bacteria (25).

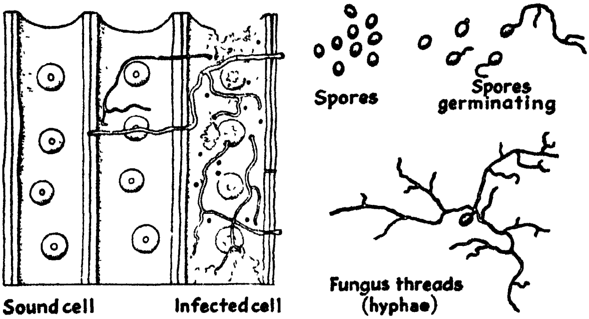

Fig. 9.—Spores and hyphae of a wood-destroying fungus. (*U.S. Bureau of Plant Industry drawing.*)

analogous in function to the root system of ordinary green plants.

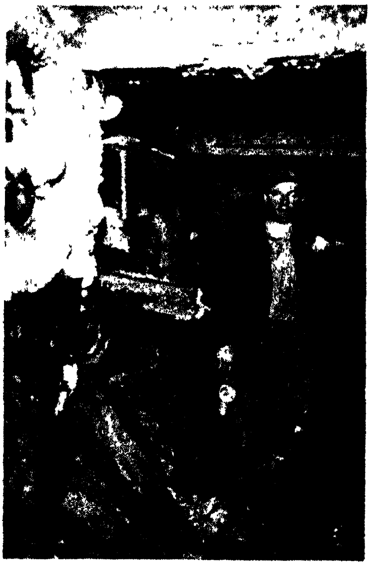

Fig. 10.—Fluffy growth of fungus mycelium over the surface of mine timbers. The warm humid air in the mine encourages fungus growth on the surface as well as within the wood. (*U.S. Forest Products Laboratory.*)

In the earliest, or *incipient*, *stage* of decay the hyphae spread through the wood in all directions from the point of inception, usually passing from cell to cell through "bore holes" (Figs. 8 and 9), which they form in the walls at the points of contact, rather than seeking out the natural openings (pits). During this invasion stage, there is no definite dissolution of the wood or visible change in its character, other than a possible discoloration of the infected piece. However, the color changes, which often accompany incipient decay, are seldom marked and may be easily confused with those produced in the chemical staining of wood (page 48). Furthermore, they are more apparent on the freshly exposed surfaces of unseasoned wood than on dry material and usually pass unnoticed on products that have been exposed to the weather during air seasoning.

Once decay has progressed beyond the incipient stage, the outward appearance of the wood is more and more perceptibly altered. The cell walls become definitely disintegrated, and the wood undergoes marked changes in color, texture, continuity, and strength properties. In the late, or *advanced, stage* of decay, the wood may become punky, soft and spongy, stringy, ring-shaked, pitted, or crumbly, depending upon the nature of the attacking fungus and the extent of its work (16).

In addition to the general color effects, the activities of decay-producing fungi may result in narrow and irregular lines of various colors but mostly dark brown or black. The origin of these *zone lines,* which are generally found only in the so-called white rots, is imperfectly understood and they are of uncertain diagnostic value. However, when they accompany incipient decay, they are of considerable importance, since they may afford the only macroscopic evidence of the presence of the fungus in the wood.

Decay Requirements.—The conditions necessary for the development of decay-producing fungi in wood are fourfold: (*a*) a supply of suitable food, (*b*) a sufficient degree of moisture, (*c*) at least a small amount of air, and (*d*) a favorable temperature. A deficiency in any one of these requirements will inhibit the growth of a fungus, even though it may be already well established in the wood.

The *food* required for the nourishment of a wood-destroying fungus is supplied chiefly by the actual wood substance (cell walls) of the host, although the starches, sugars, and other materials stored in the cell cavities may also be drawn upon. In its natural state, the highly complex combination of cellulose and lignin, which constitutes the wood substance, is not suitable for the use of the fungus. But, by the secretion of certain chemical substances, known as ferments or enzymes, the hyphae are able to break down the cell walls into simpler nutritive compounds which are soluble and can be readily assimilated by the fungus.

Based, for the most part, on their preferential chemical reactions on the constituents of the wood substance and the resultant general color effects, two broad types of decay may be recognized. The fungi in one group (designated as the *white rots*) tend to remove more lignin than cellulose from the wood, leaving behind a generally whitish cellulose complex, which usually occurs in pockets or streaks of varying size separated by areas of firm wood; in some instances, however, the fungi concentrate their attack on the cellulose but bleach the residual substance to a whitish color. The fungi in the second group (*brown rots*) generally make a more concentrated attack on the cellulose and leave a brownish carbonaceous residue, which can be readily crumbled into powder.* There are also types of decay intermediate between these two.

Few, if any, of the decay-producing fungi are able to attack all kinds of wood indiscriminately, presumably because of dissimilarities in the chemical composition of different woods, and especially the character of the infiltrated materials, or to variations in the nature of the enzymes secreted by different fungi. Some of them confine their activities to a certain group of timbers, while others are apparently restricted to a single host species. However, some woods are susceptible to attack by a number of fungi, and it is not uncommon to find two or even more of them developing in a given stick.

While the individual fungi show considerable variation in their precise *moisture* requirements, it is recognized that a moisture content considerably above what is designated as the fiber-saturation point† of wood is required for the optimum development of most of them. At that point, which occurs within the limits of 25 to 30 per cent moisture content in most woods, growth is greatly retarded, and below 20 per cent it is completely inhibited. Consequently, sound wood that has been kiln dried or thoroughly air dried is immune to decay unless subjected to wetting or to dampness sufficient to raise its moisture content above the required minimum. Moreover, if wood in which decay is already established is dried to a moisture content below 20 per cent, the development of the fungus will be arrested. However, the plant may merely remain dormant until the requisite moisture conditions are restored, and, when the wood is subjected to alternate wetting and drying, the development of decay may be intermittent. The precise length of time during which the hyphae may remain alive, though dormant, under air-dry conditions varies with the different fungi and may be a matter of years in certain cases (14). It is this ability of the hyphae to revive with the return of suitable moisture conditions which makes the use of infected timbers undesirable, and even dangerous, in buildings and other types of construction.

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* These types are sometimes designated as *delignifying* and *carbonizing* decays, respectively, while certain European authorities favor the use of the terms *corrosion* type for the white rots and *destruction* type for the brown rots.

† At the fiber-saturation point, the cell cavities are considered to be completely devoid of moisture, while the walls are fully saturated. It is upon the "free moisture" occurring in the cell cavities that the fungi are apparently dependent for their development.

An exception to the foregoing minimum moisture requirements is sometimes claimed for the so-called *dry rot* fungi,* which are frequently found growing in comparatively dry situations in factory and house timbers, or even in piles of stored lumber, and consequently are popularly believed to need little or no moisture for their development. Actually, the dry rot fungi are incapable of growing in dry wood, but they differ from the other wood destroyers in having the ability to transport moisture to the point of attack from some source of supply. Thus, once such a fungus has begun its development in damp wood or soil, abundantly supplied with moisture, it is able to spread for a considerable distance, moistening and decaying wood that would otherwise be dry and sound. It often gains a foothold in damp basements or in timbers in contact with the ground and may extend for 20 ft. or more up through the walls or other parts of a building. The conduction of water is carried on by means of minutely porous, rootlike strands of mycelium, sometimes an inch or more in diameter, which spread over the surface of the wood and also frequently span brick walls, stone foundations, and the like to reach sound timber. The most serious of these fungi in this country is the so-called "building poria," *Poria incrassata,* which has become particularly destructive in the Gulf States and the Pacific Northwest and is reported as being capable of attacking all native commercial species of wood. Several species of *Merulius,* including the *M. lacrymans* which does extensive damage to buildings in Europe, at times cause loss in wooden structures in the northern part of the United States and in Canada. (17, 18.)

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* The term "dry rot" is often applied to the late stage of those brown rots in which the wood becomes brittle and crumbly, especially after it dries out. Such a designation is clearly erroneous, since no wood will decay while it is dry. If used at all, the term is best confined, as it is in this text, to the condition produced by *Poria incrassata* and *Merulius* spp.

The development of decay is also retarded or inhibited by a redundance of moisture, although the resultant deficiency in the supply of available air in the wood is actually the significant factor. As the moisture content of wood is increased beyond the upper limits of the optimum range for a particular wood and fungus, the rate of decay decreases until finally a point is reached at which fungus growth entirely ceases. As indicated in Table II, the moisture contents representing both the upper limit of optimum growth and the inhibition point of decay have been found (27) to vary according to the specific gravity of the wood. This is in keeping with the recognized fact that the maximum water- (and air-) holding capacity of wood is primarily dependent upon its density.

TABLE II.—RELATION BETWEEN SPECIFIC GRAVITY OF WOOD AND MOISTURE REQUIREMENTS OF DECAY*

Wood	Specific gravity†	Upper limit of optimum growth, per cent m. c.‡	Inhibition point of decay, per cent m. c.‡
Sitka spruce	0.34	150	190 to 200
Southern pine, sapwood	0.44	100	145 to 150
Douglas fir	0.54	70	110 to 120
Southern yellow pine	0.70	50	75 to 80

* Six species of fungi were used in this investigation, *viz.*, *Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *T. subroseus*, *Fomes roseus*, and *Lentinus lepideus*.

† As determined from specimens used in this investigation.

‡ Moisture content, based on oven-dry weight of wood.

Decay is usually found in wood that is in direct contact with damp ground or in locations where moisture collects and cannot readily evaporate. The ends, undersurfaces, and plate- and rail-bearing areas of crossties; the ground line of posts and poles; the bases of porch columns; sills placed on the ground; the ends of beams built into concrete or masonry piers or exterior walls; and the lowest steps of porches are among the locations where decay normally starts. In addition, extensive damage sometimes occurs in interior building construction, where for various reasons the moisture content of the wood in certain parts of a structure becomes abnormally high. This is particularly the case in textile and paper mills and canning factories, in which a high atmospheric humidity is maintained. Since wood tends to come into equilibrium with the moisture in the surrounding air, dry timbers exposed to such atmospheric conditions may absorb sufficient water to make them susceptible to attack by wood-destroying fungi. This absorption of water is especially marked in the inadequately insulated roof timbers of such buildings, particularly during cold weather, when the outside temperature cools the wood and causes the moisture in the air within the mill or factory to condense in contact with the timbers; under such circumstances, the moisture content of the wood may be raised considerably above the fiber-saturation point and produce very favorable conditions for decay. For the same reason, localized decay in buildings is sometimes started in wood in contact with cold-water pipes which "sweat," owing to the condensation of the moisture from the surrounding air.

In other instances, failure of wood through decay has been noted when unseasoned material, or timber that has been seasoned and subsequently exposed to rain and fungus infection, is used without provision for adequate ventilation about it. Beams, posts, girders, and the like, put in place in a relatively wet condition and fully enclosed by metal, masonry, plaster board, or other covering that prevents the drying out of the timbers will afford ideal conditions for fungus development. In such cases, decay commonly progresses undetected, and serious, unexpected losses may occur.

A supply of *air* is necessary for the growth of wood-destroying fungi, but the demands in this respect are very moderate, and under ordinary conditions the amount within and surrounding wood in service or in storage is ample. Even the interiors of trees and large unseasoned timbers usually contain enough air in the cells to permit the development of fungi, when other conditions are favorable. It has been indicated (27) that an amount of air equivalent to more than 20 per cent of the volume of the wood must be available before decay can take place. There is a natural relationship between the air and water supply of timber and its susceptibility to rotting, since wood that is saturated with water, or practically so, is devoid of sufficient air for fungus growth and consequently does not decay.* Such is the case with waterlogged pieces as well as with wood buried deeply in the ground. The air supply in the soil becomes progressively less below the surface and at depths of five or six feet may be inadequate for decay, especially in dense, compact soils. It is primarily because of the deficiency of air in the wood that submerged piling, supporting the masonry foundations of bridges or large buildings, is not subject to decay in service.

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* This relationship is indicated in Table II, since the given inhibition moisture contents rather closely approximate the recognized maximum water-holding capacities of woods of the denoted specific gravities.

Wood-destroying fungi are capable of development over fairly wide ranges of *temperature* but make their most rapid growth during the warmer (and more moist) periods of the year. The optimum temperature varies with the individual species but in most cases appears to lie between 75 and 90°F. A study (19) of 64 species and strains of wood destroyers, most of which are commonly found in various parts of the United States, indicated that the most favorable temperature for practically two-thirds of the fungi investigated falls within this range; the lowest recorded optimum was 68°F.; the highest, 97°F. Many of these fungi developed rapidly over a relatively wide range of temperatures around the optimum, while others made their best growth within much narrower limits. The results obtained in this investigation suggest that these most favorable temperatures, as determined under controlled laboratory conditions and with media other than wood, are somewhat higher than the probable optima for long-time timber decay.

As the temperature falls below the range for most favorable development, the rate of growth of a given fungus decreases; and at sufficiently low temperatures, the plant becomes dormant, though no degree of cold, such as occurs naturally, will kill it. The inhibition point varies for different fungi. At 54°F., the lowest temperature used in the above-mentioned investigation, the growth of many of the species was only 5 to 10 per cent as rapid as at the optimum; in a few cases, development was entirely checked at that point; while in others, it was retarded about one-half to two-thirds. In another study (20) of the cardinal temperatures for mycelial growth on cultural media, the determined minima for three different fungi were 32, 41, and 44.6°F.

An increase in temperature above the favorable range has an even more marked effect in retarding development, and the application of sufficient heat will kill even the most resistant fungus. The dry rot fungus, *Merulius lacrymans*, is outstanding in its intolerance of temperature changes above the optimum, its growth being totally checked at about 82°F. In fact, the marked heat sensitivity of this fungus is held to be responsible, at least in part, for the fact that it causes only limited damage in the United States, although very destructive to buildings in northern Europe. The higher summer temperatures and the greater heating of buildings are suggested (4) as definite limitations to its more extensive development in this country.

In the above-mentioned investigation of the temperature relations of fungi (19), the growth of all but one of the species and strains studied was stopped at 115°F.; approximately three-fourths of the fungi ceased growing at 104°F. or below; and about two-fifths of them were inhibited at 93°F. or below.

The lethal temperatures of the various fungi are of particular significance in the sterilization of infected wood by heat. None of the wood destroyers is able to survive commercial kiln-drying or steaming treatments, provided that sufficiently high temperatures are applied for periods long enough to insure the penetration of the heat at least to the depth to which the hyphae have progressed. In a study of the effects of kiln drying on infected wood, in sizes up to and including 4 by 4 in. in cross section, Hubert (14) found that 16 days' exposure to temperatures of 120 to 135°F. and humidities of 70 to 100 per cent killed all of seven species of fungi which were originally present in the several different hardwoods and softwoods used in the test. He also demonstrated that pieces up to 4 in. thick could be sterilized by being steamed at 100 per cent humidity and a temperature of 120°F. for 24 hr., or 145°F. for 3 hr.; timbers 6 by 6 and 8 by 8 in. square were sterilized upon being subjected to saturated atmosphere at 130°F. for 9 hr. Chidester (6), working with sticks 1 sq. in. in cross section, found that a temperature of 150°F. for 1 hr. was adequate for sterilization. Moist heat is recognized as being much more effective than dry heat in killing wood-destroying fungi; experiments with ¾- by ¾- by 1-in. blocks, inoculated with five different species commonly found in mills, showed that none of these wood-destroyers was able to withstand a 12-hr. exposure to a moist heat of 131°F., while a dry heat of 221°F. was required to kill all the fungi during a like exposure period (26). The fact that wood can be sterilized effectively by heat does not mean, however, that such treatments will render it in any way immune to subsequent decay, if it is again exposed to conditions favorable to fungus development.

Some attention has been given to the possibility of arresting decay in certain types of factories and mills by subjecting these buildings to as high a temperature as can be obtained with the available heating systems (13). Such a treatment is decidedly limited in its effectiveness, however, particularly since the safe maximum that can be reached is only about 115°F. It may afford some measure of control of certain "low-temperature" fungi in buildings of moist occupancy but is not practicable in checking the development of those "high-temperature" wood destroyers which cause serious deterioration in the roof members and certain other parts of paper and textile mills, canning factories, dye houses, etc. (26).

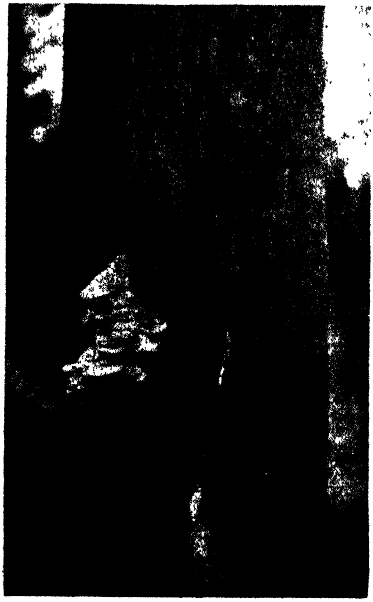

Fig. 11.—Sporophore (fruiting body) of the fungus *Polyporus sulphureus*, growing on an old chestnut pole.

Spread of Decay.—The propagation of wood-destroying fungi is accomplished by means of microscopic spores, which are comparable in function to the seeds of higher plants. They are borne in vast numbers in or on fruiting bodies (sporophores), which develop on the surface of infected wood as the result of the consolidation of masses of mycelium at favorable points on the exterior of the decaying timber. The sporophores vary greatly in shape, color, texture, and structural features and often provide a ready means of identifying the causal fungi. Some of them are of the toadstool (umbrella-like) type; others take the form of bracket- or shelf-like outgrowths from the decaying timber (Fig. 11); while still others spread over the surface of the wood in the form of leathery incrustations. Since the formation of these fruiting bodies is contingent upon the accumulation of abundant reserve food material, their presence is a direct indication of the extensive development of hyphae within the wood.

The spores are minute and extremely light and are readily blown about over wide areas by the wind, as well as being distributed by insects, birds, and other agencies. Coming into contact with susceptible timber, they are able to germinate, under proper conditions of temperature and moisture, giving rise to hyphae which penetrate the wood and thus start a new infection (Fig. 9). Warm, humid weather is most advantageous for the casting of spores from the fruiting bodies, as well as for their germination, and the spread of decay is consequently most rapid during rainy periods in the late spring and the summer. Certain fungi also form secondary spores directly on the threadlike hyphae, and these may aid, to some extent, in distributing decay.

Decay may also be spread, without the formation of spores, by the direct growth of mycelium from infected wood (or ground) to sound timber in contact with it. This frequently happens in air-seasoning yards, when green wood, in the form of lumber or various other timber products, is piled on decayed stickers, stringers, or foundations. When there is sufficient moisture in the air, the mycelium may even develop on the surface of the wood and spread on the exterior for considerable distances, at times actually growing over inert substances like brick and cement to attack sound wood. Decay is often spread by such surface growth of mycelium in mines (Fig. 10), in the concealed portions of buildings, in the lower parts of poorly constructed lumber piles, and in other inadequately ventilated situations where the atmospheric moisture is high.

Effect of Decay on Wood Properties.—As decay-producing fungi develop, they tend to alter certain of the physical and chemical properties of the infected wood, the intensity of such changes depending primarily on the extent of the decay and the specific effects of the organism producing it. The normal color of the wood is more or less definitely modified, and, in certain types of decay, distinctive odors are imparted to the rotting wood. The strength and density of the material may be drastically reduced, and its susceptibility to seasoning defects increased, while certain other properties, such as heat and electrical conductivity, may also be affected. The decomposition of the wood substance may also have a significant effect on the yields of certain products obtained in the chemical industries.

In the late or advanced stage, all decay-producing fungi cause a serious reduction in the strength and density of wood. In their earlier stages, however, there appears to be a marked difference in the degree of weakening brought about by the various fungi, especially between the so-called white rots and brown rots. Thus, the white rot fungus, *Fomes pini* (the most prevalent decay in softwoods), causes little or no loss of strength in its incipient stage; while such brown-rot fungi as *Polyporus schweinitzii*, *Fomes pinicola*, and *F. laricis* (all common softwood decays) have a decided weakening effect at an early period in their development (7). A pronounced reduction in bending strength also accompanies the early stages of attack by *Trametes serialis*, a brown pocket rot of softwood timber, even though the wood does not show much change in density, color, or general appearance (5). Similar effects were noted in regard to crushing strength, although the reduction in this property was not so rapid in the very early stages of fungus attack; furthermore, the reduction in the compressive strength was found to be closely correlated with loss in weight of the test specimens, although a slight loss in strength was observed before the reduction in weight was measurable (2). Scheffer (24), experimenting with *Polyporus versicolor* (a white rot) in red gum sapwood, found perceptible loss in specific gravity within 13 days. The modulus of rupture, hardness, and crushing strength decreased more rapidly than the specific gravity. One of the characteristic effects of incipient decay is that it often imparts a pronounced brashness, or brittleness, to wood, so that the infected material tends to break suddenly under stress, with but little deformation and with a more or less smooth and unsplintered fracture. Brashness, however, may also be caused by other factors (10) and, consequently, is not an infallible indication of the presence of decay.

Decay is considered by some investigators to be a contributing factor to the development of certain seasoning defects, such as collapse, honeycombing, and checking, but there is no unanimity of opinion on the matter. Hubert (16) attributes the collapse, which commonly occurs in kiln-dried hardwoods having "mineral stain" and kiln-dried redwood and red cedar showing "brown streak," to the weakening of the cell walls by the hyphae present in these discolored areas. He also calls attention to the occurrence of honeycombing in the mineral-stain areas of kiln-dried maple. Other investigators do not believe that fungi have anything to do with mineral stain.

Since wood-destroying fungi have a direct effect on the chemical composition of the cell walls and are the cause of discoloration, softening, and loss of weight of infected timber, the yields and quality of pulp obtained from decayed wood are naturally impaired. Rotted material has been found to be unsuitable for mechanical pulp, while in the chemical processes the type of decay has an important bearing on the results obtained. Tests (21) on the effect of a few species of fungi on spruce and balsam fir, pulped by the sulphite process, have shown that wood attacked by the brown rots, such as *Fomes pinicola*, will give low yields of pulp, while that infected by the white rots, as *Fomes pini*, may furnish relatively high yields per unit weight of wood. Other factors to be considered are the degree of softening of the wood, since this affects its ability to withstand the mechanical abrasion involved in such operations as barking, chipping, and screening, and the strength, color, and other significant properties of the pulp produced. Preliminary work on the destructive distillation of sound and infected birch and maple indicates that the yields of acetate of lime, wood alcohol, and charcoal are reduced in the decayed wood, although it is reported that wood-distillation operators are not in complete agreement with these findings (16).

Durability.—The durability of wood, or the natural resistance that it offers to decay, is an extremely variable property. Certain kinds of timber are noted for their marked resistance to fungus attack and are commonly recommended for use where untreated material is to be placed in contact with the ground or in other exposed situations; other species are considered more or less intermediate in durability; while still others are known to be readily susceptible to deterioration. But even within a given species of wood there is apt to be a marked diversity in decay resistance, so that the service life of timbers cut from different trees, or even pieces taken from the same tree, may vary over rather wide limits. The factors responsible for the differences in durability are numerous and diverse, some of them having to do with conditions within the wood itself; others, with circumstances attending its use. The species of the attacking fungus also has an important bearing on the rate of deterioration of the wood.

The sapwood of all common American woods is readily susceptible to decay, whereas in many kinds of timber the heartwood is relatively resistant to such deterioration.* In Table III, most of the common American species are listed in relative durability classes, on the basis of the resistance that their heartwood offers to fungus deterioration *when used under conditions favorable to decay*. These data are compiled from the available service records of the U. S. Forest Products Laboratory, supplemented by general experience.

It should be borne in mind that, in view of the recognized variations in durability in a given species, this tabulation is in the nature of an estimate of approximate averages and is intended merely to afford general comparisons of the relative decay resistance of the listed groups of species. Results obtained with individual pieces or installations may vary widely from the average. The "very durable" group is rather broad, yew, black locust, and osage orange being much more durable than chestnut or black walnut.

The greater natural durability of heartwood over sapwood, in those species in which such a distinction exists, is attributed primarily to certain chemical changes that take place when and after the sapwood is transformed to heartwood. The exact nature of these alterations is not thoroughly understood, but they apparently involve the deposition in the cells of the heartwood of certain materials, collectively called *extractives*, which are formed when the parenchyma (food-storing and -distributing) cells lose their protoplasm and die. Thus, the heartwood of southern cypress and some of the cedars contains essential oils; that of other cedars and redwood contains water-soluble chemicals of high toxicity; that of the resinous pines is characterized by varying amounts of turpentine and pine oil; and that of white oak and chestnut is infiltrated with tannins. Such extraneous substances, being more or less toxic to decay-producing fungi, tend to prevent or retard the development of their hyphae. A somewhat similar durability may be artificially imparted to wood by impregnating it with creosote, zinc chloride, or other toxic preservatives which serve to poison the food supply of the fungi.

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* This is in distinct contrast to the condition existing in the living tree, in which the heartwood is the part normally subject to decay, since the moisture content of the sapwood in the tree is so high as to reduce the available air supply below the minimum necessary for fungus development.

TABLE III.—RELATIVE DURABILITY OF HEARTWOOD OF COMMON AMERICAN WOODS*

Softwoods (conifers)	Hardwoods
Class 1. Very Durable	
Cedars (practically all)	Catalpas
Cypress, southern	Chestnut
Junipers	Locust, black
Redwood	Mulberry, red
Yew, Pacific	Osage orange
	Walnut, black
Class 2. Durable	
Douglas fir (dense)	Locust, honey
Pine, southern yellow (dense)	Oak, white
Class 3. Intermediate	
Douglas fir	Gum, red
Larch, western	Oak, chestnut
Pine, southern yellow†	
Tamarack	
Class 4‡	
Hemlocks	Ashes
Pine, lodgepole	Beech
Spruces	Birches
	Hickories
	Maple, sugar
	Oaks, red
	Poplar, yellow
	Sycamore
Class 5. Nondurable	
Firs, true	Aspen
	Basswood
	Cottonwood
	Gum, black
	Gum, tupelo
	Willows

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* The species in each class are listed alphabetically and not in order of relative durability.

† Including shortleaf, loblolly, and nondense longleaf pines.

‡ The heartwood of the species listed in class 4 may be considered on the border line between the intermediate and nondurable groups and cannot with assurance be placed in either group.

An investigation of the hot- and cold-water-soluble constituents of a number of different woods indicated that the relative toxicity of the heartwood extractives to the fungus "Madison No. 517," one of the more resistant fungi, is, in general, directly comparable to the recognized relative durability of the species from which they were obtained (12). Among the 10 woods studied, the one definite exception to this correlation was noted in red oak. Although the water-soluble substances obtained from this particular wood were found to have nearly the same toxicity as those of white oak, the red oak belongs to a definitely lower durability class than the other species (Table III). As a possible explanation of this discrepancy, it has been suggested that the marked porosity of the red oak leads to a rapid leaching of the toxic substances when the wood is placed in contact with damp ground or exposed to the action of rain and melting snow. Since the amount of these extractives present in a piece of wood will have a definite bearing on its service life, when used under conditions that favor decay, it is apparent that differences in the quantity of these substances in individual timbers may account for much of the variation in heartwood durability that occurs within a given species.

In those woods which are characterized by comparatively durable heartwood, the relative amount of sapwood present in untreated timbers will naturally have a decided influence upon their serviceability when exposed to conditions that favor decay. Thus, in the case of a pole or post, the complete decay of a thin ring of sapwood at the ground line may not seriously impair the usefulness of the piece, whereas the destruction of a wide band of sapwood will probably result in the failure of the timber, even though the heartwood is not attacked. In the latter instance, the decay resistance of the heartwood is of little or no consequence in determining the service life of the timber. In some species, such as black locust, chestnut, northern white cedar, and western red cedar, the sapwood is rather uniformly narrow (usually less than 1 in. in width), while in others it may be quite wide (up to 6 in. or more); in most woods, the width of the sapwood is definitely influenced by the conditions of growth (10). Since heartwood formation is a factor of age, the size of the tree from which a given timber is cut has an obvious bearing on the amount of sapwood the piece contains. Thus, crossties and other timbers cut from small tree trunks have a higher proportion of sapwood than those made from more sizable stems. Furthermore, the type of product involved may also have a significant effect, since pieces, such as crossties and construction timbers, that are sawed or hewed to a square or rectangular cross section may have much, if not all, of the sapwood removed in the process of manufacture. It should be noted at this point, however, that, while the exclusion of sapwood may be very expedient from the point of view of the serviceability of untreated timber, the ease with which it can be impregnated in most species makes its inclusion highly desirable in material that is to be treated with preservatives.

The density of wood, or its weight per unit volume, might be expected to serve as a criterion of durability, since it is dependent primarily on the amount of wood substance (cell wall) present in a given piece. As applied to different species, however, it shows little or no correlation with decay resistance, since that property is influenced chiefly by the toxicity of the extractives present in the wood. Thus, certain light-weight woods, such as northern white cedar and chestnut, rank appreciably higher in the durability scale than some of the decidedly denser species, such as beech and the hickories. Within a given species, on the other hand, durability will probably increase somewhat with the increase in density, although here, again, distinct variations in amount of extraneous material will have a much more significant effect in determining decay resistance. The rate of decay and other factors being equal, the heavier pieces of a given kind of wood may be expected to have a longer service life than the lighter ones, when attacked by the same fungus.

It is sometimes contended that the preliminary seasoning of timber that is to be used untreated in contact with the ground will definitely increase the natural resistance of the wood to decay. This is not borne out by experience, however, since such authentic records as are available for poles, posts, mine timbers, and railway ties clearly indicate that there is no distinctive difference in the service life of air-dried and unseasoned timber. The wood soon reaches an approximate moisture equilibrium with the soil in which it is set; if dry, it will take up moisture from the ground, while if green, it may give up moisture to the soil. The outstanding advantage of seasoning, in so far as it affects the subsequent durability of wood, is to be noted in the enclosed parts of buildings or other confined places. Wood with a high moisture content, built into spaces where it cannot dry out readily or entirely surrounded by metal, plaster board, or similar covering, may be seriously decayed in a relatively short period of time. Adequately seasoned timber, used in the same situations, will remain sound as long as it is kept dry.

Climatic conditions have a marked effect on the service life of untreated timber, since warm, humid weather is more favorable to the decay of wood in exposed situations than relatively dry or cold weather. Thus, a given species of wood may be expected to have a distinctly shorter life in the Gulf states than in the arid Southwest or the colder Northeast or Middle West. Furthermore, the climate has some effect on the point of deterioration of such products as poles and posts. It has been observed, for example, that in the high altitudes of the Rocky Mountain states, decay usually occurs at or near the ground line, whereas, in the Southern states, it frequently extends for considerable distance above the ground and also is found in the tops of the timbers.

The season of the year when wood is cut is sometimes claimed to have a pronounced effect on its natural durability. Timber felled during the winter months is frequently considered as inherently more resistant to decay than that cut at other times of the year, although there is no unanimity of opinion as to the most preferable cutting season. This reputed inherent superiority of timber cut at one season or another is not borne out by fact, although it is definitely recognized that seasonal climatic differences, in so far as they affect the activities of fungi (and insects), may work to the advantage of winter-felled wood. However, regardless of the season of cutting, timber that is unpeeled, left in contact with the ground, or placed in poorly constructed seasoning piles may become infected with decay during warm weather before it is put into use. In fact, in some warm, humid sections of the country, railroad ties and other forms of construction material may develop more or less decay in seasoning piles, even with the best of outdoor piling conditions.

The opinion is frequently advanced that timber cut from a dead tree is less durable than that from a living one. The justification for such a contention depends upon the circumstances involved in the killing of the tree. Where death is due to the attacks of wood-destroying fungi, or where decay has gained a foothold as the tree has been gradually weakened and finally killed by other causes, the serviceability of the wood may be greatly impaired; this is especially true when the fungus concerned is one that is able to continue its development after the wood is placed in service. On the other hand, trees killed by fire, or other agencies that do not affect the quality of the wood, should yield timber as durable as that from live trees of similar quality, provided that it is utilized before the wood is subsequently injured by decay. Even living trees may be seriously infected with heart rots, so that the mere fact that a tree is not dead does not guarantee its freedom from decay. If the trees are left standing on the stump too long after being killed, the sapwood and even the heartwood may become infected with wood-destroying fungi and seriously deteriorated before the timber is adequately seasoned. However, just as serious deterioration may take place in timber from live trees if it is not properly cared for after being cut. It should be borne in mind that the great bulk of the wood in a living tree is dead, since only a comparatively small proportion of the sapwood cells contains living protoplasm.

Wood-staining Fungi

Closely allied to the wood destroyers are certain other fungi, which give rise to definite discolorations in wood without noticeably affecting the continuity and texture of the material. There are a number of these wood-staining fungi, producing a wide range of color effects; but by far the most important, from an economic point of view, are those that cause the so-called *blue stain* of various hardwoods and softwoods. It is estimated that this one defect of lumber and other wood products has been responsible for an annual loss of millions of dollars, but the loss has been greatly reduced in the last decade through the development of improved stain-prevention treatments. The strength and general usefulness of the stained stock are not destroyed, unless serious decay has also developed, but the salability and selling price are greatly reduced. Since the stain detracts from the appearance of wood, it naturally lowers the grade and price of material that is to receive a natural finish, such as interior trim, door stock, and window sash. Unstained wood is also demanded in certain grades of cooperage, box boards, veneer container stock, vehicle and implement wood, and export material. Far less serious are the fungi that produce the grayisholive stain of hardwoods, the yellow stain of hardwoods, and a number of other minor discolorations, ranging from pink, red, and brown to black (15, 16).

Blue stain, or sap stain, as it is also known, is a very common defect in a large number of woods, especially the southern and western pines and the southern hardwoods (sap gum, yellow poplar, magnolia, tupelo, black gum, and oak). The causal fungi (mostly *Ceratostomella* spp. and *Graphium* spp.) are distinct from the wood destroyers in that they obtain their nourishment from the extraneous materials stored in the cell cavities of the sapwood rather than from the actual wood substance. Furthermore, in passing from cell to cell, their hyphae generally seek out the natural openings (pits) instead of boring through the walls. It is only in the rays, in which the requisite food substances are concentrated, that the cell walls are apt to be seriously broken down. The objectionable bluish to bluish-black or brown color is produced by the massing of the relatively dark hyphae within the light-colored wood. In the Ceratostomellae, the spores responsible for the propagation and spread of the fungus are produced in small, flask-shaped fruiting bodies, which develop on the surface of the blued wood. To the unaided eye these fruiting bodies look like minute black specks, but under a hand lens they take on the appearance of small black hairs, somewhat bulbous at the base.

Blue stain may develop in the sapwood of the susceptible species in various stages of manufacture, during storage or transportation, or even in the finished product, provided there is sufficient moisture and air in the wood, and the temperature is favorable. The stain may also develop in logs and standing trees (Fig. 12), as the result of infection carried beneath the bark by the invading beetles (22). Since a moisture content of more than 20 per cent (based on the oven-dry weight of wood) is necessary for fungus growth (9), and at least a small amount of air must be available, infection and the spread of the stain may be prevented by rapid surface drying of the wood or by keeping the material thoroughly wet. The optimum temperature range for the development of the blue-stain fungi appears to be from 75 to 95°F.; growth is practically stopped at temperatures below 45°F. and above 100°F., while a temperature of 130°F. will kill the fungi if maintained for a sufficiently long period (1). Owing to the extremely favorable moisture contents of logs and of green lumber which is piled for seasoning, or shipped without provision for adequate ventilation, fungus infection and development are most prevalent in such material. At first, the stain appears as a spot or small patch or streak on the surface of a board or the end of a log, but it may soon become too deep-seated to be removed by surfacing and may eventually involve the entire sapwood. During warm, humid weather, unseasoned sapwood lumber may become noticeably discolored within two or three days after being sawed. It will be noted that these conditions, which favor the development of the staining fungi, are also conducive to infection and subsequent deterioration by the decay producers.

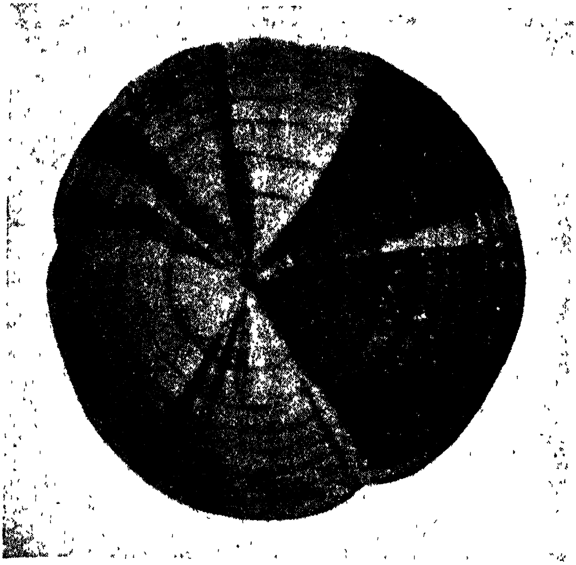

FIG. 12.—Blue stain in an insect-killed pine tree. The infection probably started from fungus spores carried under the bark of the tree by the invading insects. (*U.S. Bureau of Plant Industry.*)

The results of such reliable tests as have been made indicate that, while the blue-stain fungi may weaken wood somewhat, they do not usually decrease the strength of timber sufficiently to make it unfit for ordinary commercial use. The most definite effect is a reduction in those strength properties which relate to the shock resistance (toughness) of the wood. In general, it may be said that blue stain should not be considered as a serious defect in material to be used for ordinary construction purposes, especially when an adequate factor of safety is used in designing the structure concerned. It is sometimes claimed that blued wood is more difficult to impregnate with preservatives than unstained material, but recent investigations have served to disprove this contention. In fact, one series of tests on ponderosa and loblolly pines, in which the moisture content of the sapwood was controlled, indicated not only that the penetration and absorption of creosote and zinc chloride are greater in blued than in unstained wood, but that these treatment factors are actually improved with an increase in the degree of staining (23). The reputed difficulty of penetrating blued wood is probably due to some other condition, such as the relatively high moisture content often associated with the infected timber.

Chemical Stains.—In addition to the discolorations produced by fungi, wood is also subject to certain stains that result from chemical changes in the materials infiltrated in the wood cells. The precise nature and causes of these changes are not definitely known, although the claim has been made that, in some cases at least, they involve the oxidation or fermentation of certain organic compounds which are largely confined to the sapwood. Such stains are found in both softwoods and hardwoods, sometimes appearing in logs that have been stored for prolonged periods but usually developing in lumber during seasoning. The most important are the so-called *brown stains*—yellow to dark-brown discolorations which are especially prevalent in sugar and ponderosa pines and may develop during air seasoning (*yard brown stain*) or kiln drying (*kiln brown stain*). Although they have no effect on the wood, other than to alter its appearance, these stains may cause serious monetary loss through the degrading of the lumber in which they are found. These chemical brown stains are often confused with *brown sap stain,* a fungus discoloration affecting the sapwood of ponderosa, red (Norway), and white pines. These and other chemical stains are also mistaken at times for the discolorations produced by the incipient stages of certain decays, in which cases they may be responsible for the rejection of perfectly sound wood. (15.)

Molds

True molds, similar to those that form on damp bread or cheese, may develop in wood, producing cottony growths on the surface which range in color from white and other light shades to black. The inception and spread of these fungi are dependent upon favorable temperatures and the presence of an abundant supply of moisture, such as occurs when unseasoned wood is piled so that little or no drying can take place. Carloads of green lumber may mold in transit, especially during warm, humid weather; and in kiln-drying stock for long periods at high humidities and at low temperatures (below 135°F.), the fungi may develop to such an extent that the circulation of air through the pile is seriously reduced. Adequate ventilation of unseasoned lumber in storage or during shipment will prevent the development of these fungi, while the mold growth that appears during kiln drying may be destroyed by steaming the wood at 170°F. and 100 per cent humidity for one hour.

Mold is objectionable chiefly because of the appearance that it gives to the infected material. The superficial growth can be easily brushed or dressed off the wood, and the causal fungi do not appear to affect the strength or other important properties. Mold, however, may be a serious defect in stock that is to be manufactured into containers for certain types of foodstuffs which are subject to possible contamination. Furthermore, there is always the possibility that moldy wood may also contain decay, since the conditions that promote the growth of the true molds are also conducive to the development of wood-destroying fungi.

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CHAPTER III

AGENCIES OF WOOD DETERIORATION (*Continued*)

WOOD-BORING INSECTS

The loss in forest products of various kinds, resulting from deterioration by wood-boring insects, has been very conservatively estimated at $45,000,000 annually (20). The damage occurs in standing trees, green saw logs, unseasoned lumber and other products, and in seasoned material in storage and in use. Much of the loss is nonpreventable, particularly as it applies to standing timber, although even there it can doubtless be materially reduced by suitable forest management. In the case of saw logs and converted forms of wood, however, marked savings can be effected by the proper handling of material and by the application of preservatives where practicable.

In most instances, the damage by wood-boring insects is done in the larval stage, the larvae or grubs burrowing through the wood to obtain both food and shelter and often making characteristic galleries or holes. In some cases, however, the adult forms take an active part in the deterioration. This is notably the case with the subterranean termites, whose adult "workers" are the destructive individuals; with the mature ambrosia beetles, which often penetrate the wood for considerable distances for the purpose of laying eggs and rearing their young; and with the carpenter ants. The resultant insect holes or burrows not only affect the appearance of the wood but, by breaking up the continuity of its fibers, reduce the structural strength of the material.

For the purpose of this discussion, the wood-boring insects may be grouped into two classes: (*a*) those that confine their activities to various forms of wood before it is put into use and (*b*) those that attack wood in service. There is a certain amount of overlapping, since some of the insects that fall in the first group may cause considerable damage to unpeeled logs used in rustic structures, unpeeled mine timbers, etc.; likewise, some of those in the second group may be active in saw logs and in unseasoned lumber and other forms of wood in storage or piled for air drying. However, as they pertain to the subject at hand, the two classes of insects are sufficiently distinct in their effects to warrant segregation. The group of insects working in material in service is by far the more significant to the wood-preserving industry, since much of the deterioration by these borers can be prevented by suitable preservative treatment of susceptible timbers. It is also the more important group from the point of view of the financial losses involved, inasmuch as the replacement of the badly weakened members of a structure may involve labor and other charges that far exceed the purchase price of the new timbers.

The insect defects produced in wood before it is placed in service may be classified as *pinholes* or *grub holes*, the distinction being principally a matter of size. The former are defined as small, round, usually open holes, ranging from 1/100 to 1/4 in. in diameter; the latter are oval, circular or irregular holes, 3/8 to 1 in. in diameter, and in some cases filled with boring dust which does not fall out when the wood is jarred. Pinholes are made in the heartwood and sapwood of various softwoods and hardwoods by ambrosia beetles or timber worms, which attack living trees as well as saw logs and unseasoned lumber, timbers, bolts, and cordwood. Grub holes are made in standing trees, saw logs, and piled unseasoned lumber and other forms of wood by a variety of insects, including the flat-headed borers, Parandra borers, locust borers, pine sawyers, carpenter ants, carpenter bees, and a number of others; they infest the heartwood and sapwood of all kinds of timber. (20.) Since the extent of the damage caused by these insects is generally apparent when lumber, timbers, and other products are graded, impaired material may be degraded or rejected, depending upon the character and severity of the attack and the intended use of the wood. Insect defects may disqualify wood for specialized uses, which involve exacting strength requirements (vehicle, implement, and airplane stock), impermeability (tight cooperage), or appearance (furniture and cabinet work), and yet not render it unfit for less exacting service. Under extreme conditions, of course, the wood may be so completely riddled with insect holes, or so severely affected by associated decay, as to have no utility whatsoever.

In the following paragraphs, the discussion is confined to the most important of the insects that are capable of seriously deteriorating wood after it has been placed in service, and are consequently susceptible to control through preservative treatment and the application of other preventative measures. Carpenter bees, caddis-fly larvae, and various other insects occasionally cause damage to wood in service but do not appear to be of sufficient importance to require attention by the wood-preserving industry or discussion in these pages. Termites are the outstanding wood-destroying insects, but considerable damage is also caused by powder-post beetles and, to a lesser extent, by carpenter ants.

TERMITES*

In the United States, termites have assumed a position of major importance among the organisms responsible for the deterioration of wood in service. These insects are found in practically all sections of the country but are especially destructive in the South Atlantic and Gulf states, in the Southwest, and along the Pacific Coast. They infest a variety of structural timbers, such as poles, posts, piles, mine props, oil derricks and other wood towers, and bridge timbers, but particular significance is attached to their activities in buildings of various types. They do considerable damage to sills, joists, studs, and other supporting members of dwellings, barns, and various commercial structures (Fig. 13), although they rarely, if ever, bring about the collapse of such buildings. Their presence is generally revealed by localized failures of door casings, window frames, flooring, etc.

It is conservatively estimated (24) that termites cause a loss of $40,000,000 annually in the United States. In that part of the country south of a line drawn from Maryland to Nebraska, the depreciation of farm buildings due to termite activities is estimated to be approximately 1 per cent per year; this means an annual loss of about $29,000,000 in this region alone (14). Investigations in various cities and towns in California have indicated that termites are present in 20 to 90 per cent of the dwellings of the ordinary type or in posts, fences, walks, flower stakes, and other wooden structures on the premises (14). As long ago as 1926 it was reported (2) that 80 per cent of the frame buildings in New Orleans and 50 per cent of the business buildings in Pasadena, Calif., had been damaged by these insects. Even in those sections of the country in which infestations are relatively light, serious losses are frequently reported.

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* For an exhaustive discussion of the biology of termites and recommendations for the prevention and control of termite damage, the reader is referred to Kofoid *et al.* (14) and Snyder (23). Other references (11, 13, 15, 16, 21, 22, 24) are listed at the close of this chapter.

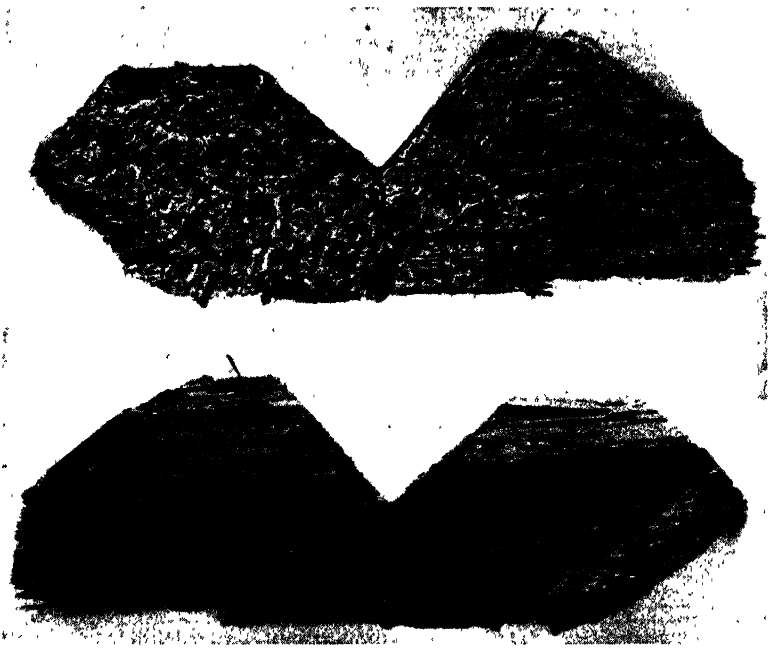

Fig. 13.—Interior (upper) and exterior (lower) views of a stair riser, riddled by subterranean termites after five years of service. (*U.S. Bureau of Entomology and Plant Quarantine.*)

In many cities in the heavily infested areas, revisions of the building codes have been made, or are being contemplated, in order to control termite damage. However, since a very large proportion of the structures that are exposed to serious injury do not come under such imposed building regulations, the amount of good that can be accomplished by codification alone is limited. If termites are to be held in check, those interested in the problem must enlist the cooperation of engineers, architects, builders, and others concerned with the design and construction of, and the purchase of timber for, buildings, pole lines, bridges, and other structures subject to deterioration by these insects.

Termites are frequently referred to as "white ants," but such a designation is erroneous, since these insects are not true ants, nor are they generally white. The use of this term is also unfortunate in that it may lead to misconceptions concerning the habits and methods of control and elimination of the pests. Termites are most closely related to the roaches, although they have few of the characteristics of these scavengers. They are social insects, living in colonies and dividing their essential activities among specialized forms or castes. There are usually three such castes in a given colony, *viz.*, the reproductives, the soldiers, and the workers; but in certain species of termites the last-named form is lacking; and in one genus there is no soldier caste (14).

In the early stages of development of a termite colony, the sexually mature reproductives normally consist of a single primary king and queen, the sole ancestors of all of the other members of the colony. During the first year of her reproductive life the queen lays but a few eggs, but her ovaries subsequently become gradually enlarged, with a resultant elongation and swelling of her body. In consequence, there is a rapid increase in the egg-laying powers of the queen, and the number of individuals in the colony soon increases to many hundreds (dry-wood termites) or many thousands (subterranean termites).* It is stated (14) that so long as the primary king and queen remain alive, the development of the reproductive function is apparently inhibited in all the other males and females in the colony. But with the death of either member of the royal pair, a supplementary king or queen is produced, and this takes over the generative duty. A pair of these supplementary reproductives also makes its appearance when a small group of termites migrates or is accidentally isolated from the main colony. The ability of termites to develop these secondary kings and queens makes it possible for an established colony to continue its existence indefinitely, so long as the supplies of food and moisture are adequate and the insects are protected from ants and other enemies.

* **For a classification and discussion of the several major groups of termites see pp. 61 to 64.**

From the eggs laid by the primary or supplementary queen are hatched the nymphs, which subsequently develop, through several growth stages, into the adult soldiers, workers, and alates or reproductives (Fig. 14). The soldiers, charged with the protection of the colony, are sterile, wingless, and without functional eyes, and vary in length from less than ¼ in. (subterranean termites) to about ⅜ to ½ in. (dry-wood species) or even ¾ in. (damp-wood species). They are distinguished by their relatively large, colored heads and heavy jaws, which are adapted to fighting but are useless for excavating the wood or feeding. When the

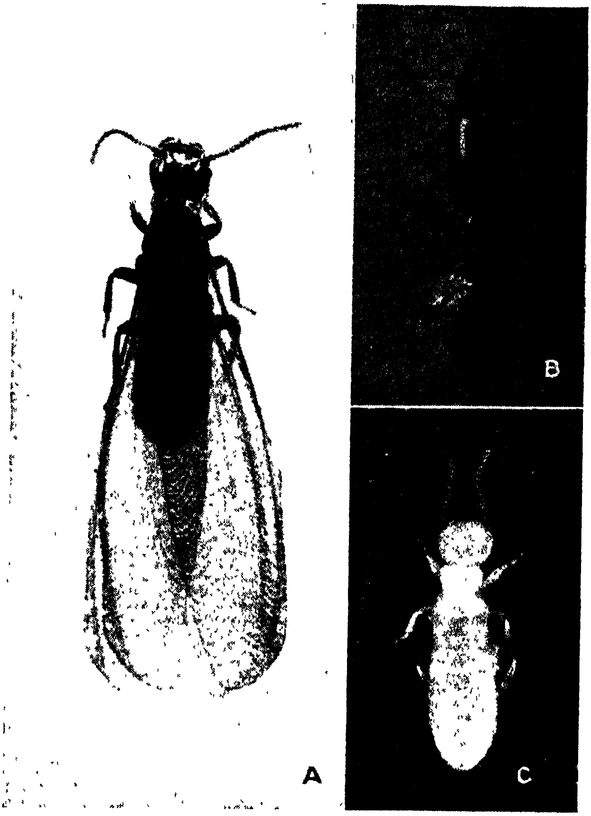

FIG. 14.—Winged reproductive or alate (*A*), soldier (*B*), and nymph of reproductive (*C*) of the eastern subterranean termite, *Reticulitermes flavipes*, considerably enlarged. (*Connecticut Agricultural Experiment Station.*)

burrows of a colony are purposely opened to the exterior for the ejection of fecal pellets or to allow the alates to emerge, or the protective shell of wood is accidentally broken down, these soldiers ward off the attacks of their natural enemies, the true ants, and of termites from other colonies. They block the small openings with their hard heads and either kill the invaders with their mandibles (mandibulate soldiers) or discharge a sticky substance which effectively stops the attack of raiding insects (nasutiform soldiers).

In the subterranean termite colonies, the workers are by far the most numerous individuals. Like the soldiers, they are sterile, wingless, and blind, and their light-colored bodies are somewhat less than ¼ in. in length. Although they are equipped with relatively inconspicuous jaws, their mandibles are especially adapted to biting off fragments of wood, and this caste is responsible for all of the destruction caused by the subterranean species. To these workers are assigned such duties as the construction and enlargement of the burrows and other structures that house the colony, the collection of food, the care and feeding of the other adult forms and the young, and the daily grooming of the various individuals in the colony. The primary purpose of this grooming habit (trophallaxis) is to provide an exchange of body secretions or exudates between individual termites, but it also serves to keep the insects' bodies free from molds and mycelium which may develop in great profusion in the insect burrows. In contrast to the subterranean species, the dry-wood and damp-wood termites have no specialized worker caste, and the immature nymphs perform the various duties of the colonies. After a period of such servitude, these nymphs mature and become either soldiers or alates.

Alates, or winged reproductives, are to be found at definite seasons of the year in all normal two-year and older colonies, being developed from certain of the nymphs over a relatively short period (up to 3 months) preceding their flight. They are more nearly like ordinary insects than the other termite forms, having somewhat flattened, usually dark-colored bodies and large, black, compound eyes, and are often called "flying ants." They attain a length of ½ in. or more (up to 1 in. or more in the damp-wood termites) with their wings. So long as they remain in the colony, the members of this caste are sexually immature; it is only after they have emerged, completed their flight, and mated that they become functional reproductives. The flights, or swarms, of these alates take place once, and sometimes twice, each year and afford one of the outstanding indications of the presence of termites in a structure or timber. The exact time of swarming is dependent upon a favorable combination of conditions outside the colony, especially abundant warmth and soil moisture. Throughout most of their geographic range in the United States, the alates of the subterranean species make their flight during the day sometime in late April or early May. On the Pacific coast, however, a more important swarming occurs following the first autumn rains. Although their flight is usually short, the alates may sometimes be carried for a distance of several miles by the wind. On alighting, the insects proceed to rid themselves of their cumbersome wings and pair off. Only a relatively small proportion of the paired individuals succeed in escaping from ants, birds, and other natural enemies and in finding suitable locations for their future activities, and these dig into the earth or wood in the earth (subterranean species) or eat their way into wood above the ground (dry-wood and damp-wood termites), to become the primary kings and queens of new colonies. It is thus that termite infestations are spread.

Termites invade wood for the twofold purpose of obtaining shelter and securing the food necessary for their growth and development. For sustenance they are dependent chiefly on cellulose, which together with lignin goes to make up the cell wall, or actual wood substance. However, they are apparently unable to utilize this material directly, and the fragments of wood that they eat are actually digested by the thousands of Protozoa that swarm in the intestines of all of the common species of termites. These tiny, one-celled animals presumably break down the complex cellulose into sugars and thus make it available to the host insects. Furthermore, it is probable that the bacteria and fungi, which are likewise to be found in abundance in the intestinal tracts of the common termites, assist in the digestion of the cellulose. It has recently been suggested (13) that the fungi, which also develop in profusion throughout the burrows (at least in those of the subterranean and damp-wood species), provide the proteins that are undoubtedly essential to the growth of the insects.

Termites are primarily inhabitants of forested regions,* deriving the major portion of their food supply from dead and fallen trees and branches and from stumps and dead roots; but with the advance of human colonization and the cutting of timbered areas for settlement and agricultural purposes, they have been attracted to the various structures and products made of wood.

Since termites definitely avoid the open air and live completely cut off from the rest of the world, except during the brief swarming flight of the alates, they give little outward evidence of their presence in wood. Even though a timber may be more or less completely riddled in the interior, the protective outer shell will remain intact, unless it is broken down by some other agency, such as decay, or through mechanical failure of the wood. The surface of the timber is opened up temporarily by the termites themselves only to permit the exit of the alates or, in the case of the dry-wood and damp-wood species, to provide for the removal of the fecal pellets. Such small openings are quickly closed, however, and any other localized failures in the exterior shell are promptly walled off by dams, which the workers or nymphs construct out of particles of wood or dirt cemented together by their excretions. It is interesting to note that the protective instinct of these insects is such that they seldom excavate the infested wood to the point that it will fail of its own weight. It is only when added loads or new stresses are imposed on a riddled timber that failure is apt to occur.

Each termite colony is an independent unit, entirely free from contact with other colonies, even of the same species of insect. Its members live in intercommunicating galleries within the wood or, in the case of the subterranean termites, in connecting burrows in both the earth and the wood. This isolated condition of the colony is significant in the protection of the termites against ants and other natural enemies as well as against contagious diseases which so often control the populations of other forms of animal life. It also makes the application of control measures somewhat difficult, especially when the extermination of the insects is attempted by means of poison dusts and gases. The habit of living in closed burrows also gives the termites some measure of control over the temperature and moisture conditions, and probably also over the oxygen pressure, within their dwellings. In fact, the air within the closed galleries may be humid to the point of saturation. This is especially true with the subterranean and damp-wood species, which require more moisture for their development than do the dry-wood termites.

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* Some species of termites inhabit desert or semidesert regions, living on the cellulose of bushes, grasses, and animal dung.

The moisture and also the temperature conditions that are conducive to the activities of most termites are such as to favor the development of decay-producing and other wood-inhabiting fungi. Furthermore, the insect galleries provide avenues for the spread of fungus mycelium and may also permit the development of fruiting bodies and spores. Thus, the deterioration of wood may become a joint undertaking of decay and termites, although the wood-destroying fungi may continue their development long after a termite colony has disappeared.

While termites are most abundant and destructive in the tropical regions of the world, they are also prevalent over much of the warm-temperate area, and a few species are able to live in the colder portions of the temperate zones. It has been indicated (14) that the 50° mean annual isotherm marks the general limits of their range, in both the Northern and Southern hemispheres. Of the approximately 2000 living species of termites distributed throughout the world, 56 are known to occur in the United States (24). This is in distinct contrast to the situation in Europe, which has but two indigenous species. From the standpoint of their living habits, the termites found in this country can be segregated into three major groups, the subterranean, the dry-wood, and the damp-wood species. The distinctive activities of each of these groups are considered separately in the following paragraphs.

Subterranean Termites.—The insects included in this group are by nature soil inhabiting, entering wood only from the ground, and require a constant supply of moisture for their existence. They readily invade both sound and decaying timbers set in or on damp soil and also have the ability to build covered runways over impenetrable obstructions as well as to erect towers directly upward from the earth and thus reach wood removed from contact with the ground. The runways and towers, constructed of tiny fragments of earth and partly digested wood cemented together by insect excretions, enable the termites to establish suitable moisture conditions in wood that would otherwise be so dry as to be immune to their attacks. When working in a structure at some distance from a ground connection or other suitable moisture source, these insects have also been known to build exploratory hanging tubes from the wood, apparently in search of more immediate contact with the earth (18). Once they have gained access to a structure, they may extend their workings to considerable height and often reach the second and even the third story of buildings.

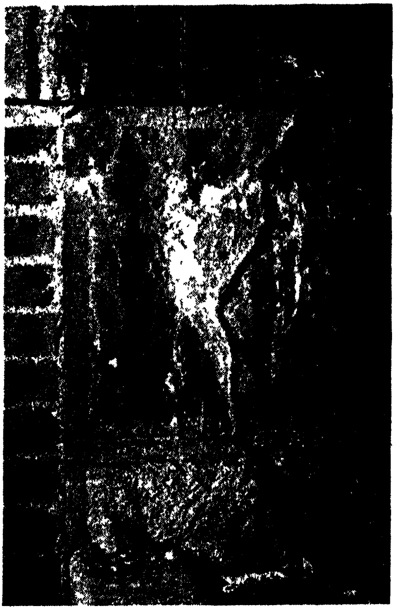

FIG. 15.—Shelter tube (runway) constructed by subterranean termites over a house foundation to gain entrance into the wood above. (*Connecticut Agricultural Experiment Station.*)

The presence of subterranean termites in a building or other structure may not be discovered until the more seriously attacked pieces of wood begin to show definite evidence of failure. On the other hand, there are certain signs, such as the occurrence of the earth-like runways over brick, stone, and concrete foundations (Fig. 15), heating pipes, and the like, and the seasonal swarming of the winged reproductives, that often indicate the existence of the insects before they have done a great deal of damage. The hollowed-out condition of badly infested poles and other large timbers may be disclosed by the lack of resonance of the wood when it is sounded with a hammer or similar tool. There are certain characteristics of the galleries of these insects that serve to distinguish them from the workings of the dry-wood and damp-wood termites. These are the oval, discolored spots made on the gallery walls by the deposition of drops of liquid feces and the peculiar *frass* (compacted masses of wood particles, dirt, and other debris) with which the insects wall up some of their cavities or plug up unused passages (Fig. 13).

Subterranean termites are found in practically every part of the United States and are responsible for most of the termite damage to wood structures. They are represented by some eight or more species of the genus *Reticulitermes* and by *Heterotermes aureus*, which is confined to the desert fringe of the Southwest. Since they work essentially from the earth, these insects cause the greatest structural weakening at the ground line of poles, posts, towers, bridge timbers, etc., and in the foundation members of buildings, where the strength requirements are most exacting. In excavating the wood, the subterranean termites tend to follow the grain; and in timbers like Douglas fir and southern pine, which are characterized by definite differences in density between spring and summer wood, they usually make a preferential attack on the softer spring wood.

Dry-wood Termites.—The insects of this group are distinct from the subterranean termites in that they are entirely wood inhabiting, never entering the ground, and require but little moisture for their existence. At the time of swarming, the winged reproductives gain entrance to sound, dry wood directly from the air. Each pair of alates seeks out a check, crack, or other small natural opening in the wood, or a crevice in the superstructure of a building, and begins to tunnel into the timber from that point, quickly plugging up the entrance with particles of chewed wood. In excavating their galleries, the dry-wood termites form tiny fecal pellets, which are occasionally discharged through holes temporarily opened up for the purpose in the protective outer shell of wood. The accumulation of these characteristic pellets at the base of, or under, the structures in which the insects are working affords a definite indication of the presence of the termites.

Dry-wood termites are able to work in wood having a moisture content as low as 10 to 12 per cent and, consequently, may be found in thoroughly air-seasoned timbers and the woodwork in the upper parts of buildings as well as in more moist material. They are reported as causing considerable injury to all aboveground parts of untreated and butt-treated poles, although in certain parts of their range they appear to concentrate their attacks on the tops of such timbers as well as invading crossarms and insulator pins. The damage to frame buildings is more or less sporadic and may occur in a great variety of locations, including studding, rafters, joists, sheathing, siding, flooring, window frames, and door casings; the attacks may also be extended to furniture and other contents of infested structures.

These termites, chiefly members of the genus *Kalotermes,* have a very restricted range in the United States, being found only in a narrow strip of territory extending from California, along the entire southern boundary of the country, and up the South Atlantic coast as far north as Virginia. Accordingly, they cause far less damage throughout the country as a whole than do the subterranean species. Even where their ranges overlap, the dry-wood termites are less injurious; their colonies are distinctly smaller than those of the ground-inhabiting group; and they do not have a permanent worker caste. However, the dry-wood termites can effectively riddle timbers with their galleries if allowed to work unmolested for a few years. Their cavities are large and irregular, and the insects apparently work in the summer wood as readily as in the less dense spring wood.

Damp-wood Termites.—Like the dry-wood termites, those belonging to the damp-wood group enter wood directly from the air at the time of swarming and have no contact with the ground. But, unlike the former group of insects, they are dependent upon an abundant supply of moisture for their existence and accordingly confine their activities largely to decaying wood. However, they may extend their galleries into the sound portions of timbers when the supply of decayed wood fails and occasionally may even attack relatively dry wood.

The only insects of this group that are of economic importance in the United States belong to the genus *Zootermopsis* (= *Termopsis*) and are confined to that section of the country west of the Rocky Mountains. They are reported (14) as occasionally causing serious damage to water tanks and fresh-water piling and to wood in contact with damp ground; in certain sections of the Pacific Northwest, they have been found attacking untreated poles, extending their galleries from the moist butts into the relatively dry and sound wood above.

Natural Resistance of Woods.—Few of the woods used for construction purposes in the United States are recognized as possessing any marked natural resistance to termite attack. Such meager service records and experimental data as are available indicate that the heartwood of redwood and southern cypress has a definite resistance, especially when used aboveground, but even these woods are seriously damaged at times. Very resinous southern pine is considered to be practically immune to attack, but the supply of such material is so limited as to give it little or no commercial significance. The preference of termites for one species of wood over another is sometimes demonstrated when more than one kind of timber is available for the extension of their colonies. Evidence of such selectivity is presented in a known instance in which dry-wood termites passed directly through redwood subflooring to expand their galleries in Douglas fir floor joists and subsequently left the fir to attack a cherry antique chest; in another reported case, subterranean termites built covered runways up a redwood post and along a redwood stringer for a total distance of 7½ ft. to enter and destroy a Douglas fir stringer and a fir replacement, without ever entering the redwood (14). Since sapwood is more attractive to the insects than heartwood, it should be excluded in selecting resistant woods for use where they will be exposed to attack by termites. The presence of even a small proportion of sapwood may enable the insects to become established in a timber and extend their galleries into heartwood which might otherwise have successfully resisted the invasion.

While the termite resistance of such woods as redwood and southern cypress is unquestionably due to the toxicity of the extractives (infiltrated chemical constituents) contained in the heartwood, the precise effects of these natural preservatives in preventing or retarding the insect damage are unknown. The extractives may have a direct toxic action on the insects themselves, or they may inhibit the growth of the fungi which are presumably essential to the termites' diet, or poison the Protozoa in the insects' digestive tracts. In fact, it is probable that the termites' attempts to extend their colonies into the resistant woods are repelled by a combination of these effects. A pronounced resistance to attack may also be produced artificially, even in the most susceptible timbers, by adequately impregnating the wood with coal-tar creosote or other suitable preservative.

The selectivity of termites is by no means a matter of merely choosing between different kinds of wood, for in attacking wooden structures these insects commonly single out certain timbers and disregard others of the same species. Thus, termites may invade certain flooring boards, joists, or studs in a frame building and ignore others that are similar in location and general appearance. This difference in susceptibility to attack may be associated with variations in hardness, moisture content, concentration of extractives, and other characteristics of the wood. In some cases, however, it probably results from the fact that the termites had a great surplus of food and insufficient time to use much of it.

POWDER-POST BEETLES

There are a number of insects that produce so-called "powder-post" defects in wood (20). The larvae or grubs of these insects bore through the wood for food and shelter, leaving the undigested parts of the material in the form of a fine powder. When an infested piece is moved or jarred, this powdery residue falls out of holes that were made in the surface of the wood by the winged adults as they emerged to spread the infestation. The larvae honeycomb the wood with their irregular and often large burrows and, when the attack is severe, usually leave little sound wood other than a thin outer shell, which may be easily broken down. Among these insects, which infest timber under a wide range of conditions, are species that attack softwoods as well as hardwoods, heartwood as well as sapwood, and green logs and lumber as well as seasoned wood. In most cases, the damage can usually be avoided by proper sanitation and prompt manufacture, drying, and utilization.

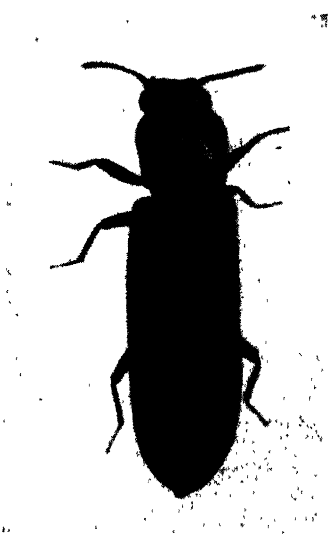

FIG. 16.—Winged adult of a *Lyctus* powder-post beetle, enlarged. (*U.S. Bureau of Entomology and Plant Quarantine.*)

The most important of the powder-post insects, from the standpoint of prevalence and extent of damage, are the *Lyctus* beetles (Fig. 16), which are found in practically all parts of the United States. These insects attack only those hardwoods in which the vessels (pores) are of sufficient diameter to receive their eggs. Oak, ash, and hickory are especially liable to deterioration, although other woods, including maple, walnut, persimmon, cherry, elm, poplar, and sycamore, are also affected. The liability of wood to attack is determined by its starch content, since starch is the principal food substance of the *Lyctus* larvae (1, 26). The injury is accordingly confined to the sapwood of the susceptible species, but even this may show marked variation in the extent to which it becomes infested, depending upon the rate of drying of the wood (12, 26) and probably also upon the season during which the timber is felled. When drying is delayed, or the timber is immersed in water after felling, the parenchyma cells in the sapwood continue their activity, and the contained starch may be entirely transformed to other materials, in which case the wood will be immune to *Lyctus* infestation. On the other hand, when the timber is seasoned rapidly or exposed to high temperatures, as in steaming, the parenchyma cells die before the supply of starch is used up, and the sapwood is consequently susceptible to attack. Furthermore, powder-post damage is generally associated only with air-seasoned or kiln-dried stock; in fact, Snyder (19, 20) states that wood seasoned less than 8 to 10 months will not be attacked. However, investigations conducted in England on oak sapwood (9) indicated that, while they preferred drier material, *Lyctus* beetles could invade wood having a moisture content as high as 40 per cent; eggs were laid and larvae developed in specimens having from 10 to 28 per cent moisture. When the moisture content fell below 8 per cent, the wood used in these experiments was not attacked.

Lumber, furniture, woodwork of buildings, implement and vehicle stock, cooperage, and other products made from the sapwood of susceptible species are often seriously damaged, and material left undisturbed in storage for prolonged periods may be so thoroughly deteriorated as to have practically no utility (Fig. 17). The decrement in seasoned hardwood products may amount to from 10 to 50 per cent of the value of such stock held by a single manufacturer or dealer, while the direct financial loss throughout the country has doubtless aggregated hundreds of thousands of dollars (19, 20).

The larvae, which develop from the eggs laid by the *Lyctus* beetles in the vessels (pores), tunnel the interior of the sapwood and leave their irregular burrows packed with the powdery, undigested remnants of wood. Under normal outdoor conditions, pupation usually takes place in the early spring, and the mature winged beetles emerge during the late spring and early summer, leaving holes $\frac{1}{16}$ to $\frac{1}{12}$ in. in diameter in the surface layers of the wood. However, when infested timber is located in storehouses, dwellings, or other buildings that are kept warm and dry, the adults may make their appearance and begin their activities much earlier. On the other hand, the life cycle may also be extended considerably, and the insects may be present in the wood for two years or more before the beetles emerge; it is stated (1) that this condition results when the amount of starch in the wood is insufficient for the normal rate of development of the *Lyctus* beetles. The emergence holes, and the powder-like

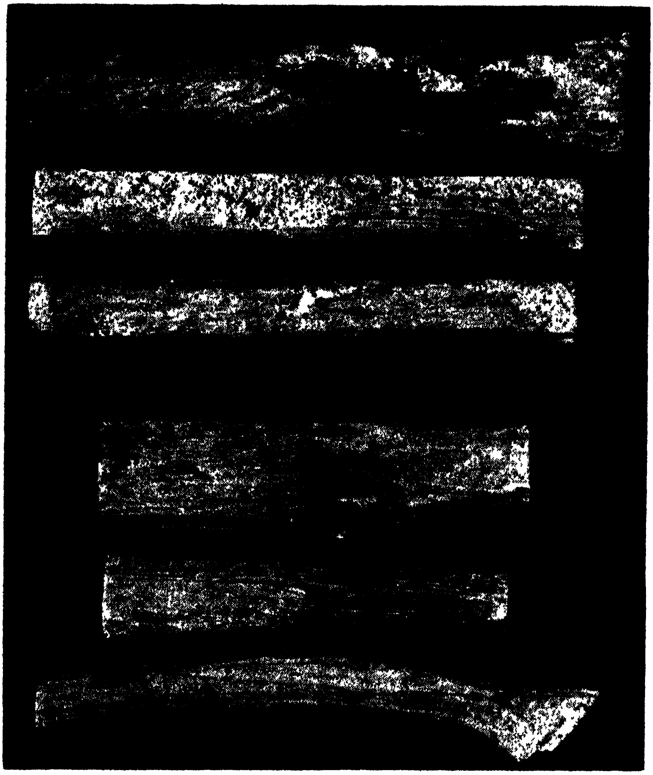

FIG. 17.—Tool handles destroyed by larvae of *Lyctus* powder-post beetles. (*U.S. Bureau of Entomology and Plant Quarantine.*)

wood residue that falls out of them and often collects in small piles at the base of, or under, infested material, serve as definite indications of powder-post damage. After mating, the female beetles go in search of suitable places to deposit their eggs. They may crawl or fly, often for some distance, to sound material and thus start a new infestation but are more apt to concentrate on near-by wood regardless of whether or not it has already been attacked. *Lyctus* beetles commonly reinfest the same timber time and time again, so long as the wood continues to furnish adequate food for the larvae.

CARPENTER ANTS

Small to large, black or brown carpenter ants are commonly found in stumps and old logs in the forest, as well as in standing trees in which the wood has been exposed by basal wounds. They may also extend their activities to wood in service, especially after decay has begun to soften the material, and sometimes cause appreciable damage to wood poles, structural timbers, or even buildings. Numerous instances of serious injury to untreated chestnut poles have been reported in southern New England during the past few years. These true ants usually gain access to timbers set in or on the ground directly from the soil but may enter buildings by crawling or by being carried in fuel and other wood. They excavate the wood for shelter, rather than for food, usually making a preferential attack on the relatively soft spring wood. They do not seriously injure the wood during the first year, but under favorable conditions may continue to enlarge their galleries until replacements or extensive repairs are required. In infested chestnut poles, these insects extend their workings as much as 2 to 4 ft. above the ground line as well as for a considerable distance below that point.

Like the termites, these true ants live in colonies and have definite castes, and their work is sometimes mistaken for that of the subterranean termites, since the burrows of the two groups of insects have a rather definite resemblance. However, unlike the termites, which commonly plug their unused galleries with a woody frass, the ants keep their runways free from all refuse. Furthermore, their workers are not so secretive as those of the termites and may be frequently seen in the vicinity of the wood they are excavating.

MARINE BORERS

Extensive damage is done to the submerged portions of marine piling and wharf timbers and to other wooden members of fixed and floating structures in salt or brackish waters by certain wood-boring animals, known under the general term of marine borers. These marine animals are widely distributed throughout the salt waters of most of the world although more prevalent and destructive in the warm regions than in the cold ones. In the United States, they are especially active along the Pacific, Gulf, and South Atlantic coasts, in certain sections of which they may completely destroy untreated piles and other timbers in less than a year. But, even along much of the New England coast, the attack has become sufficiently severe in the past few years to require protection of wood, if reasonably long life is desired (4). At times, the borers become epidemic in character, as now appears to be the case in New England, and cause serious and often sensational destruction of marine structures. The most serious outbreak in this country occurred in the northern part of San Francisco Bay, where from 1917 to 1921 the marine borers were responsible for damages estimated at $25,000,000 (10). No attempt has been made to compute the normal monetary loss in this country, but it is unquestionably high. In British Columbia, the annual loss to the piling of cannery wharves alone is placed at $100,000 (8).

There are two distinct groups of marine wood-boring animals, each characteristic in its general structure and method of attacking wood. These are the molluscan borers, distantly related to the oysters and clams, and the crustacean borers, which are kin to the lobsters and crabs. The distinctive features of these two groups are discussed rather briefly in the following pages. For more detailed information the reader is referred to publications listed at the close of this chapter (5, 6, 10).

MOLLUSCAN BORERS

Three important genera of wood-boring mollusks are found in United States coastal waters, *viz.*, *Teredo*, *Bankia*, and *Martesia*. The first two comprise a number of species that are superficially wormlike in form and are quite similar in their effect on wood and in other characteristics; they are popularly known as *shipworms*.

Borers of the genus *Martesia*, on the other hand, resemble clams in general appearance and are distinct from those of the other two genera in a number of respects.

Shipworms.—The marine borers of the genera *Teredo* and *Bankia* are reproduced from eggs, which are fertilized either within the female or in the water, depending upon the species of borer. In either event, the eggs are soon transformed into minute, free-swimming larvae which are able to move about in the water and over the surface of submerged portions of wood until they find a suitable place of lodgment. It is only during this stage that the shipworms are able to extend their attacks to sound timber, since, once development begins within the wood, the borers are imprisoned for the rest of their lives. These larvae are provided with bivalve shells, which may be made to enclose the animals when protection is needed. After a period of development, estimated at about 30 days from the time when they were first formed (5), the larvae are able to attach themselves to timbers and begin boring. These young individuals make very small entrance holes in the surface of a timber, but once within the wood they increase rapidly in size and develop the characteristic wormlike bodies for which the animals are popularly named. It was formerly considered that the shipworms bored into wood for shelter alone, but more recent evidence indicates that the wood itself is partly digested, supplementing the food supply furnished by the minute organic particles and floating organisms (plankton) found in the sea water.

As a shipworm develops in wood, it enlarges its burrow to accommodate the increasing size of its body and lines the wall with a shelly (calcareous) deposit. The method by which the burrow is excavated was long in dispute, but it is now agreed that the wood is bored by the mechanical action of the pair of shelly valves, which were formed while the animal was in the free-swimming (larval) stage and are retained at the anterior (head) end of the adult form, growing in size as the excavating proceeds. These boring shells are equipped with rows of fine teeth, resembling in miniature those on a file or rasp, and actually scrape away the wood particles. The posterior end of the shipworm is provided with two extensible tubes (the incurrent and excurrent siphons), which are normally extruded through the entrance hole on the surface of the wood. The water needed

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Shipworms are to be found in practically all of the coastal waters of the United States and are the most destructive of the marine borers. However, the extent and rapidity of their deterioration of wood vary over wide limits, being contingent upon the species of borer involved, the intensity of infestation, the abundance of food (plankton), and such environmental factors as the temperature and salinity of the water. Under conditions extremely favorable for individual development, the shipworms may attain total lengths of 1 to 4 ft. and diameters up to an inch, depending upon the species, but when they attack a given timber in great numbers the available wood soon becomes so completely occupied that their growth is curtailed, and they are seldom more than a few inches long and ⅛ to ¼ in. in diameter. These borers usually enter the wood at right angles to the grain and then begin to burrow in a longitudinal direction, following a very irregular course. When the infestation is heavy, some of the galleries, of necessity, extend rather deeply toward the center of the timber before turning with the grain. As a result of this continued honeycombing of the wood, the structural strength of a pile or other timber may be so reduced that it will fail under the slightest stress (Fig. 18).

During all the time that the shipworms are developing within wood, their entrance holes are but slightly enlarged. Consequently the interior of an infested timber may be virtually riddled at a given level, while the surface shows only slight perforations. In its early stages, the destruction is further obscured from casual inspection by the fact that the shipworms frequently concentrate their attack at or near the mud line.

Martesia.—The wood-boring mollusks of this genus resemble small clams in general appearance, since their bodies are entirely encased within the bivalve shell, even in the adult form. They are like the shipworms, however, in general structure and activities within the wood. The young individuals are free to move about in the water, and they attack piling and other submerged timbers, boring small entrance holes (⅛ in. or less in diameter) in the surface of the wood. Once within the timber, they continue their boring and excavate the wood sufficiently to accommodate the growth of their imprisoned bodies. Although relatively small—generally not over 2½ in. in length and an inch in diameter when mature—*Martesia* are capable of doing considerable damage. Their distribution along the coast of the United States is apparently limited to the shores of the Gulf of Mexico.

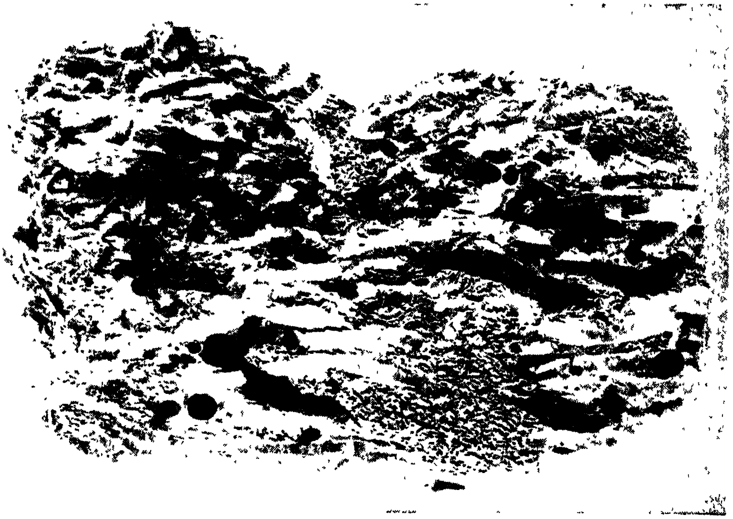

Fig. 18.—Section of spruce pile destroyed by marine borers in Alaskan waters in three years. Note burrows of both shipworms (large) and *Limnoria* (small). (*U.S. Forest Service.*)

Crustacean Borers

The wood-boring crustaceans are distinct from the molluscan borers in their methods of attacking and destroying marine timbers as well as in their general structure and appearance. Unlike the shipworms and *Martesia*, these borers do not become imprisoned in the wood but are able to move about, especially in the adult stages of their development. The young and old alike burrow into the timber, making narrow galleries (Fig. 18) which seldom extend very far below the surface. While these workings are thus more or less superficial, the animals commonly attack wood in such great numbers that the outer shell of an infested timber becomes thoroughly honeycombed at the points of attack. The thin partitions of wood separating the burrows are then broken away by the mechanical action of the water and floating objects, and a new surface is exposed to the borers. Thus the destruction is carried progressively deeper, and the volume of wood at a given level may be so reduced that the timber is no longer able to support the imposed load.

The attacks of these crustacean borers may extend to the mud line but are usually most concentrated between the half-tide and low-tide levels, where the eroding action of the waves and the battering of floating debris accelerate the breaking down of the honeycombed surface of the wood. As a result of this more or less localized destruction, heavily infested piling and similar timbers tend to assume a distinctive hourglass shape between the tide levels.

The damage done by this group of marine borers is less spectacular and serious than that caused by the shipworms, not only because it is more evident to inspection but also owing to the fact that the excavation of the wood proceeds less rapidly. Under the most favorable conditions, the crustacean borers require at least a year to bring about the failure of a 14-in. pile, while the shipworms can accomplish this destruction in a few months (5).

Three genera of this group of marine animals, *Limnoria*, *Sphaeroma*, and *Chelura*, are found in American waters. The first two belong to the order Isopoda and hence are related to the ordinary "wood lice" or "sow bugs" frequently observed in damp places, while *Chelura* is assigned to the order Amphipoda, which also contains the "sand fleas" common along ocean beaches.

Limnoria.—Of the crustacean borers, the *Limnoria* (Fig. 19) are by far the most destructive, being active along the entire Atlantic, Gulf, and Pacific coasts of the United States. Of the six known species, one, *L. lignorum*, is almost world-wide in its distribution; the others are apparently confined to certain portions of the Pacific Ocean and adjacent seas.

The segmented body of this animal has seven pairs of legs with sharp, hooked claws, which enable the individual not only to move about freely but also to cling firmly to the wood. It is also provided with thin, platelike appendages (gills), which serve for respiration and also furnish the motive power for the limited amount of swimming carried on by the animal. The mouth parts include a pair of strong, toothed mandibles designed for boring the wood, which is utilized for food. The body ends in a broad tail plate, which is used to close the burrow against intruders. The young, which hatch from eggs carried in the brood pouch of the female, differ from the adults only in size, and are able to begin boring at once. Since the ability to swim is entirely lacking in the very young individuals and decidedly limited at best in the adults,* *Limnoria* attack usually extends slowly from a center of infestation. The more extensive spread of these borers in a given harbor or other locality is presumably accomplished by the distribution of infested driftwood.

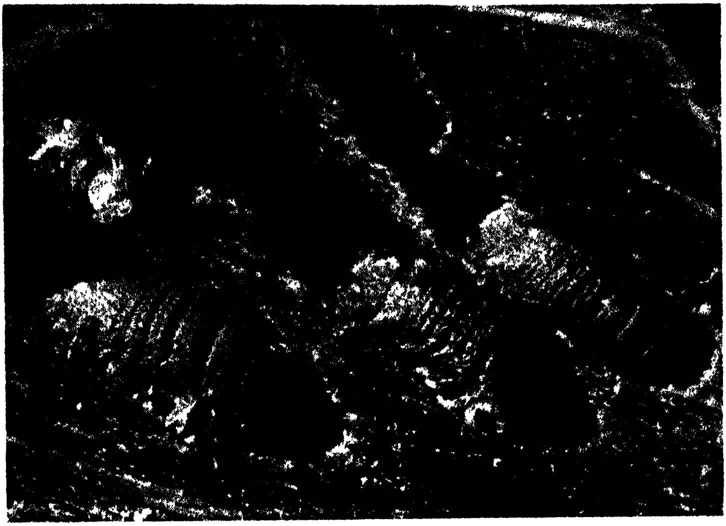

FIG. 19.—*Limnoria* burrowing in wood, greatly enlarged. (*Photograph by T. G. Townsend, U.S. Forest Products Laboratory.*)

Limnoria are only about ⅛ to ¼ in. long when mature, and their galleries seldom extend below the surface of the wood for more than ½ in., although they may run obliquely for an inch or more. The depth of the burrows is apparently limited by the inability of the borers to renew the water required for respiration at any greater distance from the surface. When, as is frequently the case, *Limnoria* invade the same timbers as the shipworms, they may eat away the wood protecting the molluscan borers (Fig. 18) and thus expose them to the attacks of their enemies.

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* The maximum linear distance that *Limnoria* has been observed to swim is about 3 ft. (10).

Sphaeroma.—The wood borers of this genus have the same general structure as the *Limnoria* but are much larger and stouter, sometimes reaching a length of ½ in. and a width of ¼ in. Their burrows are relatively wide—up to nearly ½ in. in diameter—and, while usually shallow, may attain a depth of 3 or 4 in.

These animals are rather widely distributed in American waters but are not so numerous or nearly so destructive as *Limnoria*. However, they have been reported as doing considerable damage in certain localities and occasionally have been found working in fresh water. The surface of piling partly destroyed by *Teredo* is sometimes secondarily attacked by *Sphaeroma*. These crustaceans are presumed to bore wood for shelter only.

Chelura.—The two described species of this genus are apparently chiefly active in tropical and subtropical waters, although *C. terebrans* is reported as a wood destroyer on the north European coasts and the Atlantic coast of North America. Until recently, it was considered to be of little economic importance in American waters, but Clapp (7) reports that it is now a serious menace in certain localities, causing at least as much damage as the native *Limnoria*. *Chelura* is slightly larger than *Limnoria*, with which it apparently always works in marine structures.

RESISTANCE OF WOODS

No woods are known to be naturally immune to destruction by the various marine borers, although the heartwood of certain kinds has been found to offer decided resistance to their attacks, presumably owing to the presence of extraneous essential oils or other toxic substances or to a high silica content. The most resistant species are all of foreign origin and include such woods as jarrah, totara, turpentine wood, azobe, manbarklak, angelique, and greenheart, although the last-named timber does not have an especially good record in tropical waters (5, 10). However, none of these are available for general use in this country, owing to their uncertain or limited supply and their excessive cost, and major dependence must continue to be placed on the two native woods which have been intensively used in the past for piling and other structural timber, *viz.*, southern pine and Douglas fir. Both of these are soon destroyed under heavy marine-borer attack, unless some form of artificial protection is provided.

There are a number of methods of protecting piling and other timber against the borers, but the most satisfactory and practical results are obtained by adequately impregnating the wood with coal-tar creosote or creosote-coal-tar solution. In harbors along the South Atlantic and Gulf coasts, in which marine borer attacks are especially severe and untreated wood is commonly destroyed in a year or less, thoroughly creosoted piles are estimated to have an average life of 10 to 12 years and frequently last much longer (5). In San Francisco Bay and connected waters, untreated timbers often fail within a period of from 6 months to several years, while the service life of creosoted piling is estimated at 15 to 30 years (10). On the North Atlantic coast, somewhat longer life is to be expected normally from both untreated and creosoted material. However, the attacks of *Limnoria*, *Sphaeroma*, and *Martesia* are not always stopped even by thorough creosote treatment, and shallow and erratic penetration or low absorption of preservative affords but slight protection against any of the crustacean or molluscan borers. Other methods of protection, such as the use of pile armors and various coatings and sheathings, have met with varying degrees of success and are discussed briefly in Chap. XI.

FIRE

Fire causes serious and at times spectacular damage to timber structures of various types and is popularly considered to be the outstanding agency of deterioration of wood. While the greatest importance is naturally attached to the losses in property and life incurred in the burning of frame buildings, fire is also recognized as a factor of some significance in the destruction of mine timbers and of bridges, trestles, and other structures built entirely, or in large part, of wood. From the point of view of the actual amount of wood destroyed, however, fire is quite secondary in its importance to the relatively slow-working and less obvious but omnipresent decay. Although the annual fire loss on wooden buildings and their contents is estimated at approximately $216,800,000,* only a small proportion of this amount represents the value of the timber destroyed. Labor and other charges involved in the fabrication of the damaged structures make up a far greater percentage of the total loss.

The recognized inflammability of wood has proved to be a major obstacle to its extended structural use in competition with noncombustible materials. In fact, undue emphasis on the so-called "fire hazard" of timber construction and the biased propaganda of the proponents of other materials have often led to an unjustified discrimination against the use of wood for structural purposes. In the building field, experience has repeatedly demonstrated that the use of noncombustible framing materials does not in itself insure a structure against serious damage or even virtual destruction by burning. Fuel for the inception and spread of fire is nearly always provided in any type of building by materials even more combustible than wood. Thus, the presence of inflammable furnishings and other contents, in combination with such factors as faulty construction, human carelessness or ignorance, and the lack of facilities for the quick suppression of incipient blazes, are to be regarded as much more potent fire risks than wooden construction.

While the fire hazard of timber construction has often been grossly exaggerated, the fact remains that wood is the only primary structural material that will ignite and burn at fire temperatures. For this reason its extensive and indiscriminate use is justifiably objected to in the congested sections of cities and in theaters, hospitals, apartment houses, hotels, and other large buildings. In many cities, the building codes definitely restrict the use of wood within certain zones and even prohibit it in specific types of structures. This differential treatment has led to marked improvements in the design and construction of wooden buildings and has stimulated the development of methods of making wood fire retardant. The protection of wood against fire is discussed in Chap. XII.

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* This valuation is approximately 52 per cent of the average yearly loss from fire and lightning on all property for the 5 years 1929–1933, inclusive. The total appraisement, amounting to $417,076,000, is based upon the losses reported by member companies of the Actuarial Bureau of the National Board of Fire Underwriters, the aggregate of these being increased 25 per cent to cover losses not recorded by such members.

The facility with which untreated wood may be ignited at low temperatures by a match, burning brand, spark, or other small ignition source depends to some extent upon the species involved (17). Far more significant, however, are such factors as the degree of dryness of the wood, the temperature of the heat source, the duration of the exposure, the size and shape of the wood, and the details of construction. Dry wood can be ignited more easily than moist material; and decayed wood, more readily than sound. At temperatures as low as 392°F. (200°C.), considerable time is required before air-dry wood is kindled, but the ease of ignition increases rapidly as the temperature rises; at 752°F. (400°C.) all woods ignite very quickly in the presence of a pilot flame or other medium of ignition. Since the temperature of a burning building may considerably exceed 1700°F., it is apparent that the kind of wood used has very little effect on the fire resistance of the structure.

Wood will take fire spontaneously, if exposed to temperatures above 527°F. (275°C.) for a sufficiently long period of time. The material becomes gradually charred on the surface exposed to the heat source and finally ignites.

MECHANICAL WEAR

Wood that is subjected to traffic conditions of various kinds is continually exposed to deterioration by mechanical wear, or abrasion. Such is the case with crossties; planking for railway crossings; wood block used for street and bridge pavements and for factory floors; plank flooring of piers and various platforms; wooden rollers; and certain forms of mine timber, including ties, stope floors, and lining for chutes and ore slides. In some of these uses, such as factory flooring and rollers, the wood may be rendered unserviceable by mechanical wear alone; but in most instances, decay combines with the abrasion to cause the failure of the timber. In the latter cases, the impregnation of the timber with creosote or other recognized preservative will have a twofold effect in increasing its service life, since the preservative not only prevents or retards the rotting of the wood but, in so doing, tends to maintain the original hardness of the material. Protection against wear alone is sometimes obtained by covering the portions of timbers exposed to decided abrasion with metal or other protective devices. Outstanding among such contrivances are the metal tie plates that are now extensively used on most of the railways in this country, in order to increase the mechanical life of crossties. These tie plates, which are placed between the steel rails and the ties, distribute the imposed traffic loads over a greater area of wood than is covered by the rail base alone and thus reduce the amount of wear to which the tie is subjected.

As the result of an extensive investigation of the mechanical wear of ties, the opinion has been advanced (25) that, while the deterioration may be due in part to the compression of the fibers directly under the steel rail or tie plate, it is largely the result of the actual wearing away of the wood by the movement of the metal over the surface of the tie. In this connection, it may be pointed out that, with the general adoption of preservative treatment by the railroads, the mechanical failure of crossties due to wear as well as to such injuries as spiking, checking, and splitting has now become the significant factor in determining the service life of such timbers. Previously, when untreated wood was extensively used and railway traffic was far lighter than it is at present, ties were weakened by decay to such an extent that only in the most durable kinds did the mechanical resistance of the wood play any distinctive part in determining their serviceability. Consequently, the stress was placed upon the natural decay resistance of a species; and even such relatively soft, but durable, woods as northern white cedar and chestnut were looked upon with much favor. Today, with resistance to decay increased artificially to such a point that crossties are able to withstand the ravages of wood-destroying fungi for 20 years or more, ways and means are constantly being sought to increase the mechanical life of the wood, and the dense and hard woods are preferred.

WEATHERING

When unpainted or otherwise unprotected wood is exposed to the weather, it is subjected to several different types of deterioration, the effects of which are collectively designated as weathering. The exposed surfaces of a board or other piece of wood commonly develop so-called *raised grain*, becoming rough and corrugated or fuzzy; small checks and splits appear and may eventually become large cracks which at times extend entirely through the piece; the board may warp and twist and even pull loose from its fastenings; and ultimately the surface fibers become friable and actually disintegrate so that the exposed layers of the wood are gradually worn away (Fig. 20). Raised grain, checking, and even warping may become apparent within a few weeks or months, but the wearing away of the surface layers is a very slow process and may be evident only after the wood has been exposed to the elements for a number of years. Eventually, however, the wood may be completely disintegrated. Weathering is a common cause of deterioration in unpainted and inadequately painted forms of wood, such as house and barn siding, exterior trim, shingles, board fences, signs, and stadium seats and in the tops of poles and posts. It is sometimes confused with decay, but the two types of deterioration are quite distinct, differing with respect to their causes, the conditions favoring their development, and the methods that will effectively control them (3).

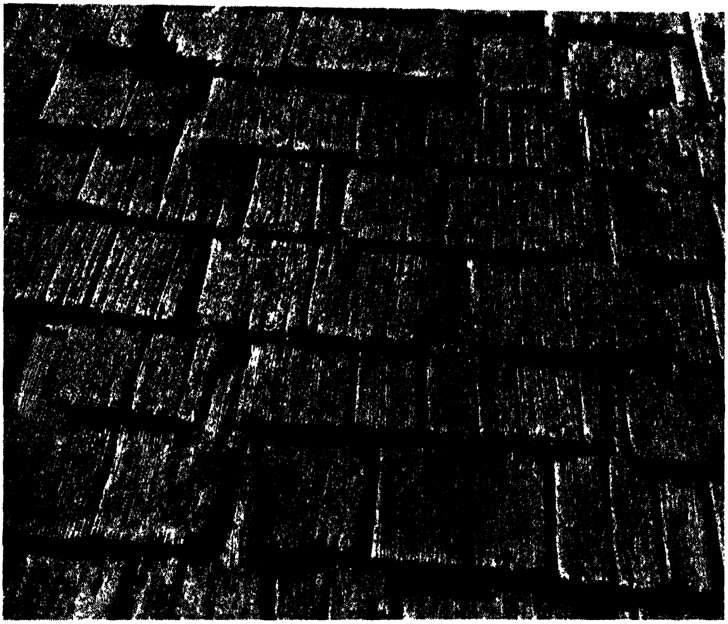

Fig. 20.—Roof shingles badly weathered by long exposure to the elements. *(U.S. Forest Products Laboratory.)*

Weathering is primarily the result of repeated dimensional changes in the surface layers of a piece of wood. Being a hygroscopic substance, wood is readily influenced by the constantly changing moisture conditions of the atmosphere, with the result that the exposed surfaces of an unprotected piece absorb moisture and swell in rainy and humid weather and give up moisture and shrink during periods of dryness. Owing to the relatively slow transfusion of water through wood, however, there is little or no change in the moisture content or the volume of the interior of the piece, unless the humid or dry condition of the atmosphere continues for a considerable period of time. Consequently, the dimensional changes are commonly concentrated in the outer shell of the wood, setting up alternate compressive and tensile stresses which eventually produce the mechanical disintegration of the surface layers. Other factors, such as the action of frost, the abrasive effect of rain, hail, and wind-blown particles of dirt or sand, and the chemical changes of the wood substance induced by light, moisture, and oxygen, may also contribute to the general process of weathering of wood.

Wood may be protected against weathering by applying paint or varnish to the surfaces that will be subject to such deterioration. While not impervious to moisture, such coatings when properly applied and adequately maintained are sufficiently effective to prevent extreme and rapid changes in the moisture content of the surface layers of the wood.

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CHAPTER IV

WOOD PRESERVATIVES

Wood preservatives are chemical substances which, when suitably applied to wood, make it resistant to attack by fungi, insects, or marine borers. The protective effect is achieved by making the wood poisonous or repellent to the organisms that would otherwise attack it. Preservatives vary widely in character, cost, effectiveness, and suitability for use under different conditions of service.

REQUIREMENTS OF A GOOD WOOD PRESERVATIVE

A wood preservative, in order to be suitable for general commercial use, should be toxic to wood destroyers, permanent, highly penetrative, safe to handle and use, harmless to wood and metal, plentiful, and economical. For the treatment of building lumber or manufactured articles, or for other special purposes, it may also need to be clean, colorless, odorless, paintable, nonswelling, fire resistant, or moisture repelling, or have certain combinations of these properties. Inability to meet at least the most important of these requirements has been responsible for the failure of all but a few of the many preservatives that have been developed in the past.

The effectiveness of a preservative depends primarily upon its toxicity, or its ability to make the wood poisonous to the organisms that feed upon it or enter it to obtain shelter. Some materials appear to be repellent toward insects without being toxic, but for protection against fungi and marine borers this poisonous property is essential. In theory, it is possible to protect dry wood against fungus attack by treating it with "waterproofing" materials which will prevent the absorption of moisture; but, in practice, this has not been accomplished. No moisture-retarding treatment yet developed is sufficiently effective to prevent decay in wood that is in contact with damp soil. Water is absorbed slowly through even the best of such protective treatments, and, in time, the wood can become wet enough to decay. Paint, despite the common belief in its efficacy, does not prevent decay.

The need for permanence in a preservative is obvious. Treated wood may be required to serve 40 to 50 years or even longer. No material that evaporates from the timber in a few years, or that changes chemically in so short a time into ineffective compounds, is suitable for wood preserving. Numerous substances, of which benzol and cresylic acid are examples, are sufficiently toxic for protection but too volatile to remain in the wood for any length of time. Others are toxic to begin with but are chemically unstable and change too quickly into products that evaporate readily or are nonpoisonous, or both. An example of this latter type of chemical is to be found in calcium cresylate, which, by combination with carbon dioxide from the air, breaks down into volatile cresylic acid and nontoxic calcium carbonate. All preservatives undergo some change in the course of long exposure to the weather, but the rate of change must be very slow if a particular chemical is to be successful.

A preservative must be capable of being forced into the wood to an appreciable depth, if a high degree of protection is desired. Surface coatings are not sufficiently effective because they are too easily broken, worn away, or checked through as the wood seasons. Solids and highly viscous materials are not suitable, because of their inability to penetrate wood.

Safety in handling and use is required in order that a preservative may be applied by ordinary wood-preserving methods and that the treated wood may be subsequently used without undue health or fire hazards. All successful wood preservatives are poisonous to man in some degree and, if taken internally in sufficient quantity, will cause severe illness or even death; but this is also true of a great many chemicals in common industrial or household use. It is only when a preservative offers a special risk that it needs to be classed as unsafe. Lead salts, for example, would be hazardous to use because their cumulative poisonous character makes them dangerous not only to workmen at the treating plant but also to users who might come in frequent contact with the wood. Mercuric chloride, which is very effective against decay, would probably have found more extensive use if it were less poisonous to man. Chemicals that may cause occupational diseases are, of course, undesirable.

Preservatives containing highly inflammable solvents add to the cost of treatment by necessitating special precautions for fire prevention and by increasing insurance rates. They may also require special care in handling and storage to prevent explosions. If the inflammable or explosive portion of the preservative leaves the wood quickly, the hazard is confined to the treating plant or the freshly treated wood.

Corrosiveness is an undesirable characteristic in a wood preservative, because it results in damage to the metal of the treating equipment and to such metal fittings and fastenings as may be applied to the wood in service. Chemicals that are markedly acid in character corrode iron, and those that are strongly alkaline destroy aluminum and zinc as well as wood. Copper sulphate and mercuric chloride both attack iron and, therefore, cannot safely be used in unprotected iron or steel equipment.

Preservatives that damage wood to any distinct degree tend to defeat the purpose for which they are used. Some substances, like creosote, apparently have no weakening effect on the wood; others, while they do not reduce most of the strength properties of timber, may possibly decrease its resistance to impact bending; still others tend to impair seriously the general strength of the wood into which they are injected. Chemicals may be injurious to wood in concentrated solution but harmless at lower strengths. Zinc chloride, for example, may actually destroy wood when injected in strong concentration, but in the solution strengths used in commercial treatments its effect is generally negligible.

It is obvious that a preservative must be inexpensive and available in sufficient quantity in order to meet the needs of the wood-preserving industry. Since chemical cost is one of the principal items in the expense of treating wood, it must be kept as low as practicable. When treating costs are lowered, the fields in which treated wood can be economically employed are extended, and the savings that result from the use of such timber are increased.

Lack of color and odor and suitability of the treated wood for the application of transparent or other finishes are important requirements when the wood is to be used for interior trim, finish flooring, doors, window frames and sash, furniture, fixtures, or miscellaneous building lumber. Lack of odor is of importance also in freight cars, refrigerator cars, refrigerators, warehouses, and other places where foods sensitive to odors may be stored.

With furniture, flooring, and similar products it is desirable that the lumber be dried and worked to final dimensions before treatment. Otherwise the preservative in the wood removed in turning, planing, and other operations will be wasted; there is also danger that untreated wood may be exposed in spots where the penetration is not of sufficient depth. The shrinkage occurring in the subsequent redrying of wood after impregnation with water solutions is apt to cause opening of joints, roughening of finished surfaces, and distortion of individual members, unless the wood is dried before final machining and installation. Preservatives applied in water solutions are thus at a disadvantage for the treatment of manufactured products. Chemicals that are suitable in other respects and whose injection does not cause the wood to swell are generally preferable for this purpose.

Resistance to fire, as well as protection against decay and insect injury, may sometimes be required in furniture or building lumber. Moisture resistance, or shrinkage prevention, may be important when wood is to be subjected to conditions that cause frequent changes in moisture content, particularly when it is desirable to keep the resultant shrinking and swelling at a minimum. However, this is not a property that it is yet practical to provide in high degree, except in small material, and it is seldom demanded that a wood preservative be also effective as a moisture retardant or shrinkage preventive.

Different chemicals possess the desired characteristics in varying degree, some excelling in one feature, and others having the advantage in different properties. No preservative yet developed is "universal," in that it meets all the requirements. The character of the wood to be treated and the service to be required of it determine the preservative properties that are most important in any particular case.

METHODS OF DETERMINING EFFECTIVENESS OF PRESERVATIVES

Some of the properties required in a preservative can be measured by laboratory methods. Toxicity, penetrative ability, chemical properties, corrosiveness, fire resistance, and effect on paint, for example, can all be studied in the laboratory sufficiently to determine whether a material considered for use as a wood preservative is acceptable in these respects. Some information can also be obtained on chemical stability and permanence, but laboratory data will generally not be sufficient to permit positive conclusions on these points. Laboratory tests on a new preservative may often show it to be so unsuitable as to warrant no further attention. But when such investigations give promising results and indicate that the new material will be effective, the conclusions must be verified by extensive observation of the utility of the proposed preservative during actual use over long periods of time. There is as yet no short cut that avoids the necessity of service tests. In fact, laboratory tests on a new preservative serve mainly to show whether it is sufficiently promising to justify making service tests. This unfortunate situation makes the introduction of new chemicals a very slow and expensive process and has done much to retard progress in the development and utilization of improved preservatives. The difficulties in this respect are very discouraging to honest promoters of promising materials, although they appear to have little deterring effect on the exploitation of questionable chemicals for which extravagant claims are often made. The use of misrepresented preservatives is especially favored when both promoter and prospective purchaser are not well informed on the subject.

TOXICITY DETERMINATIONS

Toxicity, which is usually the first property to be considered, can be measured in the laboratory under properly controlled conditions, by attempting to grow fungi on culture media containing different amounts of the preservative being studied. In that way, the minimum concentration of preservative required to kill the fungus can be determined; this concentration, expressed as a percentage of the final wet weight of culture medium, including the preservative, is designated as the *killing point* of the preservative. A concentration somewhat lower than the killing point, which prevents the growth of the fungus without causing its death, is called the *total inhibition point.* The two points should not be confused.

A preservative usually has different killing points when tested against different fungi or when the conditions of test are otherwise varied. Toxicity values, therefore, are entirely relative, so that the killing points of different chemicals are directly comparable only when they have been determined against the same organism and by exactly the same test procedure. This fact is appreciated by plant pathologists throughout the world, but, unfortunately, they have not been able to agree upon a single world-wide standard toxicity test.

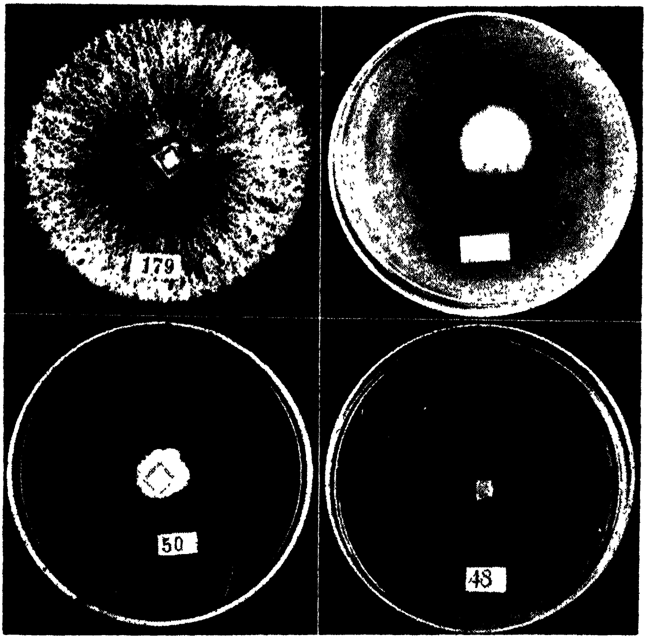

FIG. 21.—Studying the toxicity of a chemical by the American standard method, using malt-agar culture medium in Petri dishes. In dish 48, the fungus of the transplant has been able to make no growth, while that in dish 179 has spread from the transplant over the entire surface of the culture medium. (*U.S. Forest Products Laboratory.*)

In the United States, investigators have agreed upon a method in which a standard strain—"Madison No. 517"—of a fungus (formerly called *Fomes annosus*) is grown in Petri dishes (Fig. 21), or Erlenmeyer flasks (Fig. 22), upon malt-agar culture media containing different concentrations of the preservative under test (7, 31). This fungus was chosen as the standard for testing because it is quite resistant to most preservatives and grows well under laboratory conditions. It is not a very important destroyer of structural timber but is an excellent organism for use in comparative tests. Other fungi are also employed when supplementary tests are desired.

In Europe, investigators prefer to make toxicity tests on small blocks of pine sapwood treated with different concentrations of preservative and laid upon the surface of vigorously growing fungi in Kollé flasks (15, 27). The blocks are usually placed in the flasks in pairs, one untreated and the other treated, or in threes, two of which are treated (Fig. 23). Various fungi are used. The effect of a fungus upon a block is determined at the end of the test period, either by visual observation or by comparing the oven-dry weight of the block with its computed oven-dry weight at the beginning of the experiment. The effectiveness of the preservative is expressed in terms of both the lowest amount of chemical (in kilograms per cubic meter of wood) found to afford complete protection and the highest amount found to permit attack.

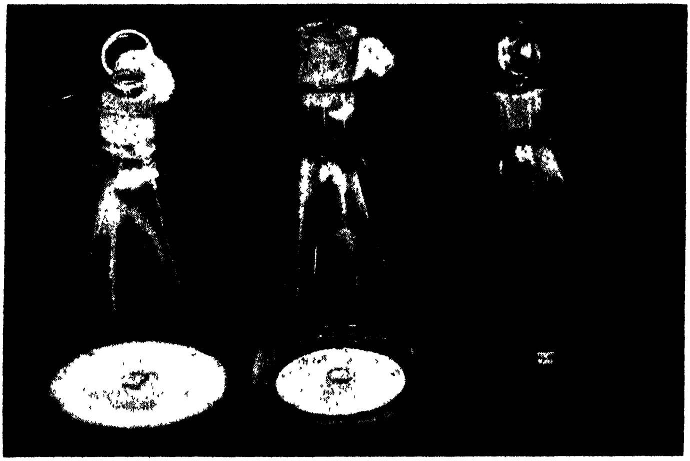

Fig. 22.—A variation of the American method, in which Erlenmeyer flasks are used instead of Petri dishes, to retard loss of moisture and volatile preservative. (*U.S. Forest Products Laboratory.*)

The Petri-dish-agar method has the advantage of greater simplicity, speed, and convenience. On the other hand, since the Kollé-flask method provides for testing the preservative in wood, its proponents claim that it more nearly measures the results to be expected in service. Both procedures are purely empirical and give diverse results with different fungi or with variations in details of manipulation. Neither simulates natural conditions or gives results that can safely be converted into minimum amounts of chemical that must be maintained in the wood to give satisfactory protection in actual service. However, both methods do give comparative information on the relative toxicities of various chemicals and, when intelligently employed, are very useful in studying recognized preservatives or new materials offered as preservatives.

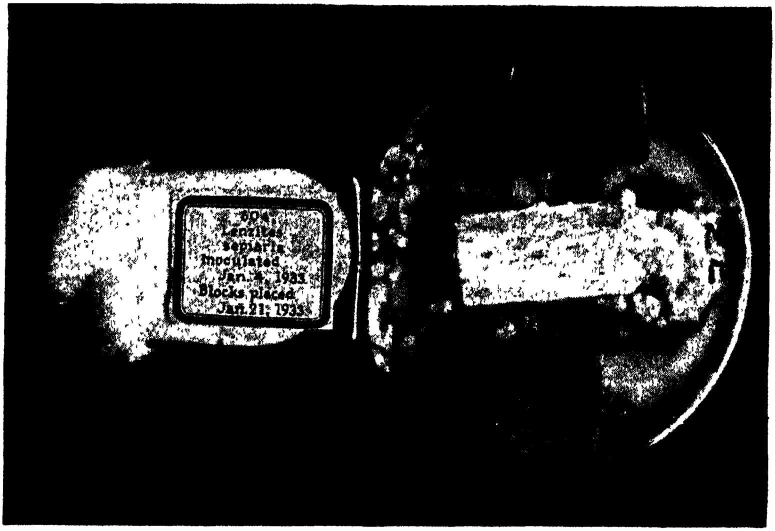

FIG. 23.—Studying toxicity by the European method. The three blocks in the Kollé flask have been exposed to the fungus *Lenzites sepiaria;* the center block (untreated) appears to be heavily attacked, while the other two (treated) show no evidence of infection. (*U.S. Bureau of Plant Industry.*)

From time to time, investigators have studied the toxicity of wood preservatives on other culture media and with organisms other than those included in the two standard methods described above (23, 32). Bacteria, yeasts, molds, and blue-stain fungi have been employed, but none of them gives results that can be considered representative of the behavior of wood-destroying fungi. Toasted bread, gelatin, sawdust, and various mixtures of agar with malt extract or other nutritive materials have been used for culture media, but investigators have now generally accepted the malt-agar formula of the American standard and the wood blocks of the European standard as most suitable.

A very recent publication (36), however, describes a new method in which wood blocks are used in small, covered glass jars provided with a water supply but with no culture medium other than wood. It is claimed to be superior to both the American and European standard methods, as a measure of the effectiveness of wood preservatives, but has not yet been sufficiently studied by different investigators to permit definite conclusions as to its superiority.

If a preservative is to be toxic to wood destroyers, it must be sufficiently soluble in the body fluids of the attacking organisms to afford a lethal dose (2, 4). Since these fluids are chiefly water, this means, in general, that the preservative must be at least partially water soluble. Coal-tar creosote is commonly considered to be insoluble in water, but actually it contains numerous compounds that are sufficiently capable of being dissolved to exert a poisonous effect. A preservative may be potentially very toxic but so slightly soluble as merely to retard the growth of a fungus without killing it. Diphenyl and acenaphthene are examples of this type of chemical. On the other hand, chemicals such as pentachlorphenol may be extremely low in water solubility, but, on account of their high toxicity, the very small amount that does dissolve may be sufficient to kill fungi. The acidity or alkalinity of the body fluids or exudates of the wood-destroying organisms, such as the enzymes that fungi exude into the surrounding wood, may also have an important influence in this connection. In theory, at least, it is possible for a preservative to be too insoluble in pure water, but sufficiently soluble in slightly acid or alkaline body fluids, to be toxic.

Toxicity Data.—The variation in toxicity of zinc chloride and sodium fluoride to different wood-destroying fungi is shown in Table IV. Table V gives comparative toxicity data for a considerable number of chemicals against the fungus "Madison No. 517." The data in both tables were obtained by the American standard (Petri-dish-agar) method.

PERMANENCE AND ACCELERATED EXPOSURE TESTS

No standard laboratory tests are available for studying the permanence of a preservative. Investigators have frequently made leaching tests, by submerging small blocks of treated wood in running water or in frequent changes of water, for long periods of time, and observing the rate of loss of preservative (18, 26). Sometimes a cycle of tests has been employed in which heating and drying have been used (supplemented by soaking or spraying), thus inducing loss by volatilization as well as by solution or leaching (17). Other investigators have made permanence tests by exposing small pieces of treated wood to the weather and making analyses from time to time to determine the amount of preservative retained in the samples (12). All of these tests are time consuming and expensive, because of the great number of chemical analyses involved, and none has been accepted as a standard for general use. Furthermore, while they can be made to give much indicative and useful information, they do not

TABLE IV.—TOXICITY OF ZINC CHLORIDE AND SODIUM FLUORIDE, AS INDICATED BY DIFFERENT SPECIES OF FUNGI*

Species of fungus	Percentage of chemical in the medium			
	Causing total inhibition		Causing death	
	Sodium fluoride	Zinc chloride	Sodium fluoride	Zinc chloride
Coniophora cerebella	....	0.25 to 0.3	. ..	0.3
"Madison No. 517"	0.2 to 0.25	0.3	0.25	0.35
Fomes pinicola	0.15 to 0.2	0.075 to 0.1	0.2	0.1
Fomes roseus	0.1 to 0.15	0.2	0.15	0.25
Lentinus lepideus	0.1 to 0.15	0.05 to 0.075	0.15	0.075
Lenzites sepiaria	0.15 to 0.2	0.15	0.2	0.25
Lenzites striata	0.2 to 0.25	0.1	0.25	0.15
Lenzites trabea	0.3	0.15	Above 0.3	0.45
Pleurotus ostreatus	0.3	0.075	Above 0.3	0.25
Polyporus schweinitzii	0.15	0.1	0.25	Above 0.6
Polystictus abietinus	0.1 to 0.15	0.25	0.15	0.4
Polystictus hirsutus	0.15 to 0.2	0.1	0.2	0.15
Polystictus versicolor	0.1 to 0.15	0.3	0.15	0.35
Poria incrassata	Below 0.1	0.2	Below 0.1	0.25
Schizophyllum commune	0.25 to 0.3	0.3	0.3	0.4
Stereum fasciatum	0.1 to 0.15	0.15	0.15	0.3
Trametes carnea	0.15 to 0.2	0.15	0.2	0.2
Trametes pini var. *abietis*	0.2 to 0.25	0.075	0.25	0.15

* Determined by Richards (29).

TABLE V.—KILLING CONCENTRATION OF VARIOUS CHEMICALS TO THE FUNGUS "MADISON NO. 517"

Chemical	Formula	Killing concentration (anhydrous compound, percentage by weight)	Reported by	Reference
Inorganic compounds				
Aluminum sulphate	$Al_2(SO_4)_3 \cdot 18H_2O$	Above 0.5	Bateman and Baechler	8
Arsenic trioxide	As_2O_3	0.025(T.I.P.)*	Bateman and Baechler	9
Borax (sodium tetraborate)	$Na_2B_4O_7 \cdot 10H_2O$	0.13	Bateman and Baechler	9
Boric acid	H_3BO_3	0.25	Bateman and Baechler	9
Cadmium chloride	$CdCl_2 \cdot 2H_2O$	0.078(T.I.P.)*	Bateman and Baechler	9
Cadmium sulphate	$CdSO_4$	About 0.14	Bateman and Baechler	8
Copper arsenate	$Cu_3(AsO_4)_2$	0.04 to 0.05	Bateman	6
Copper sulphate	$CuSO_4 \cdot 5H_2O$	0.064(T.I.P.)*	Bateman and Baechler	9
Ferric sulphate	$Fe_2(SO_4)_3$	About 0.2	Bateman and Baechler	8
Magnesium ammonium arsenate	$MgNH_4AsO_4$	0.067(T.I.P.)*	Bateman and Baechler	9
Mercuric chloride	$HgCl_2$	0.005 to 0.006	Bateman and Baechler	8
Nickel ammonium sulphate	$NiSO_4(NH_4)_2SO_4 \cdot 6H_2O$	0.035 to 0.05	Bateman and Baechler	8
Nickel arsenate (ammoniated)	....	0.03(T.I.P.)*	Bateman and Baechler	9
Nickel arsenite	$Ni_3H_6(AsO_3)_4$	About 0.03	Bateman	6
Nickel chloride	$NiCl_2$	0.0136(T.I.P.)*	Bateman and Baechler	9
Nickel chromate (basic)	....	0.012(T.I.P.)*	Bateman and Baechler	9
Nickel sulphate	$NiSO_4 \cdot 6H_2O$	0.024 to 0.03	Bateman and Baechler	8
Sodium arsenite	Na_2HAsO_3	0.044(T.I.P.)*	Bateman and Baechler	9
Sodium chromate	Na_2CrO_4	0.034	Bateman and Baechler	9
Sodium dichromate	$Na_2Cr_2O_7$	0.03	Bateman and Baechler	9
Sodium fluoride	NaF	0.25	Richards	29
Sodium hydroxide	$NaOH$	About 0.3	Bateman and Baechler	8
Sulphuric acid	H_2SO_4	0.10 to 0.15	Bateman and Baechler	8
Thallium sulphate	Tl_2SO_4	0.023(T.I.P.)*	Bateman and Baechler	9
Zinc acetate	$Zn(C_2H_3O_2)_2$	0.47 (T.I.P.)*	Bateman and Baechler	9
Zinc chloride	$ZnCl_2$	0.35	Richards	29
Zinc-meta-arsenite	$Zn(AsO_2)_2$	0.10	Curtin and Thordarson	13
Zinc sulphate (commercial)	$ZnSO_4$	0.65	Fleming and Humphrey	16
Organic compounds				
Alphachlornaphthalene	$C_{10}H_7Cl$	0.006	Bateman and Baechler	9
Beechwood creosote	....	0.12 to 0.24	Fleming and Humphrey	16
Betanaphthol	$C_{10}H_7OH$	0.015	Bateman and Baechler	9
1-Chlorbetanaphthol	$C_{10}H_6ClOH$	0.005	Bateman and Baechler	9
Coal-tar creosote	....	0.07	Bateman and Baechler	9

TABLE V.—KILLING CONCENTRATION OF VARIOUS CHEMICAL[illegible]O THE FUNGUS "MADISON NO. 517".—(*Continued*)

Chemical	Formula	Killing concentration (anhydrous compound, percentage by weight)	Reported b[illegible]	Reference
Coal-tar creosote:				
Sample 8387 (sp. gr. 1.040)	....	0.05 to 0.1	Schmitz	30
Sample 8403 (sp. gr. 1.062)	....	0.1 to 0.2	Schmitz	30
Sample 8401 (sp. gr. 1.096)	....	0.4 to 0.5	Schmitz	30
Sample 1074 (sp. gr. 1.048)	....	0.35	Fleming and Humphrey	16
Coal tar, sample 8400 (sp. gr. 1.166)	... .	0.9 to 1.0	Schmitz	[illegible]0
50:50 creosote–coal-tar solution.....................	....	0.2 to 0.6 (according to creosote used)	Schmitz	[illegible]
50:50 creosote-petroleum solution.....................	....	0.5 to 3.0 (depending on oils used)	Schmitz	30
2-4 Dichloralphanaphthol....	$C_{10}H_5Cl_2OH$	0.002(T.I.P.)*	Bateman and Baechler	9
2-6 Dichlor-4 nitrophenol....	$C_6H_2Cl_2NO_2OH$	0.01(T.I.P.)*	Bateman and Baechler	9
2-4 Dinitrochlorbenzene...	$C_6H_3Cl(NO_2)_2$	0.01	Bateman and Baechler	9
2-6 Dinitrophenol......... ..	$C_6H_3(NO_2)_2OH$	0.023	Bateman and Baechler	9
Fuel oil (sample 1103)... ...	....	Over 40.0	Fleming and Humphrey	16
Kerosene (sample 1847) ...	....	Over 40.0	Fleming and Humphrey	16
Nitrobetanaphthol.....	$C_{10}H_6NO_2OH$	0.016(T.I.P.)*	Bateman and Baechler	9
Nitrotoluene (mixed)	$C_6H_4CH_3NO_2$	0.04(T.I.P.)*	Bateman and Baechler	9
Orthochlorphenol.	C_6H_4ClOH	0.03 to 0.04	Hatfield	20
Orthophenylphenol	$C_6H_4OHC_6H_5$	0.01 to 0.02	Hatfield	20
2-Chlororthophenylphenol. ..	$C_6H_4ClC_6H_4OH$	0.009 to 0.01	Hatfield	20
Phenol	C_6H_5OH	0.10 to 0.20	Hatfield	20
Pentachlorphenol	C_6Cl_5OH	0.002	Bateman and Baechler	9
Petroleum................ ..	....	Above 10.0	Schmitz	30
Sodium dinitrophenolate . ..	$C_6H_3(NO_2)_2ONa$	0.005 to 0.009	Hatfield	19
Sodium 2-Chlororthophenyl phenolate ..	$C_6H_4ClC_6H_4ONa$	0.01 to 0.02	Hatfield	20
Sodium pentachlorphenolate	C_6HCl_5ONa	0.002	Bateman and Baechler	9
Sodium tetrachlorphenolate .	C_6HCl_4ONa	0.002	Bateman and Baechler	9
Tetrachlorphenol...	C_6HCl_4OH	0.002	Bateman and Baechler	9
Trichlorbenzene (1-2-4)......	$C_6H_3Cl_3$	0.007	Bateman and Baechler	9
Trichlorphenol (2-4-5)..... ..	$C_6H_2Cl_3OH$	0.001 to 0.002	Hatfield	20
Water-gas-tar creosote				
(Sample 2233)............	... .	6.5	Fleming and Humphrey	16
(Sample 2235)	....	0.65	Fleming and Humphrey	16
Wood-tar creosote..........	....	0.025 to 0.05	Hatfield	19

* Total inhibition point (T.I.P.) given when killing point not known.

afford a reliable measure of the relative effectiveness of different preservatives in commercial forms of timber during use. The irregular periods of wetting, drying, freezing, thawing, and exposure to sunlight occurring in actual service, as well as the variety of chemicals and fungi present in the soil, create such complicated and varying conditions of exposure that it has not yet been found possible to simulate them accurately. Consequently, there is no general confidence in the results of any accelerated permanence test yet devised.

The accelerated test that most nearly approaches the conditions of actual service involves setting small stakes of treated wood in the ground, in a location especially favorable to decay or insect attack (or in sea water, if protection from marine borers is to be determined). However, this is not a test of permanence alone, since the results are also influenced by the toxicity of the preservative. If the specimens are of small cross section, and thus have a high ratio of surface area to unit volume, rapid leaching and volatilization of the preservative will be favored, and the time required for destruction of the specimens will be materially shorter than for commercial-sized timbers. Pine saplings an inch or less in diameter (Fig. 24) have been used in this way (37), but squares or turned dowels of small cross section are just as useful and easier to obtain in uniform sizes. Two- by four-inch pieces, 18 to 24 in. long (Fig. 25), have been used in some tests (25). While accelerated tests of this kind give valuable information and are being employed to an increasing extent, they are not

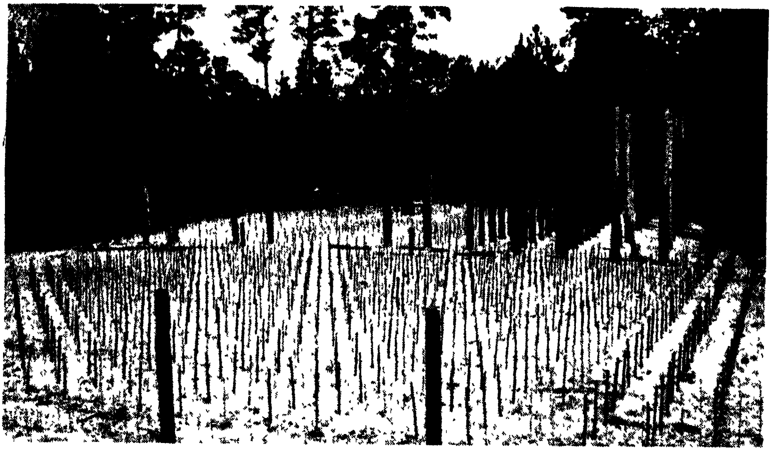

FIG. 24.—Accelerated testing of preservatives by the sapling method. Note the pole sections in the background, some with crossarms attached. (*Bell Telephone Laboratories.*)

yet considered a complete substitute for service tests on full-sized material.

SERVICE TESTS

Service tests, in order to be conclusive, must be made on commercial forms of timber in actual use under widely varying conditions of exposure. The greater the period of exposure, number of timbers, and variety of service conditions, the more convincing the results of such tests will be, other things being equal. Obviously, the records of treatment, installation, and performance of the wood must be accurate and complete in order to be of value. The principal users of treated timber in the United States appreciate the value of well-kept service records and are doing much to provide them from their own experience. Records of the life of railway ties, poles, piles, posts, and structural timbers are being published in increasing volume, especially in the annual reports of the American Wood-Preservers' Association and the American Railway Engineering Association, and are furnishing the best evidence available on the effectiveness and permanence of the more generally used preservatives.

FIG. 25.—A few of the many wood specimens exposed to termites and decay by the U.S. Bureau of Entomology and Plant Quarantine at Barro Colorado Island, C.Z. The specimens shown are approximately 2 by 4 by 18 in. in size. (*U.S. Bureau of Entomology and Plant Quarantine.*)

DETERMINATION OF PENETRATING ABILITY

The ability of a preservative to penetrate wood can usually be measured with sufficient accuracy for all practical purposes. Care is required in selecting and matching the wood specimens and in standardizing the treating conditions, so that the results obtained with the various preservatives will be strictly comparable. Determinations of penetration may be made on material impregnated under pressure or treated by a nonpressure process, according to the method to be used in actual practice, but in any case the results will be comparable only when all conditions of test are the same. The depth of penetration of such preservatives as creosote, which definitely color the wood, is easily determined by direct observation after cutting or boring the treated timber. Other substances, such as sodium fluoride or zinc chloride, while practically colorless, give strong color reactions when certain chemicals are applied to the surface of the treated wood. (See Appendix.) On the other hand, the penetration of preservatives that neither distinctly color the wood nor give practical color reactions with other chemicals is often exceedingly difficult to detect. Dyes are sometimes dissolved in the preservative solution, but the indications obtained are not at all certain, for the color does not always penetrate to the same extent as the toxic portion of the solution.

TESTS FOR OTHER PROPERTIES

Very few attempts have been made to standardize methods for testing other characteristics of preservatives, such as chemical stability, corrosiveness to metals, effect on strength or inflammability of wood, effect on appearance or durability of paints or other finishes applied to treated wood, and danger to health or comfort of workmen. With the exception of tests on the fire resistance of treated wood (Chap. XII), in which a few test methods are clearly defined, each investigator has usually preferred to devise his own procedure. Methods of testing the strength of wood are well standardized, of course, but there is room for wide variation in the choice of the strength property to be determined, the size of test specimens and methods of treatment used, the amount and distribution of preservative in the specimens, the conditions to which the specimens are exposed prior to test, and the length of time between treating and testing, all of which influence the results obtained. The health hazards involved in the use of a new preservative are especially difficult to study, owing to the general impracticability of subjecting human beings to test. Frequently, however, accumulated medical knowledge throws considerable light on the possible health hazard of a chemical proposed for wood-preserving purposes. Tests made on laboratory animals to determine the lethal dose per kilogram of body weight, as well as the effects on vital functions, may be indicative of the results obtained on human individuals.

Despite the lack of standardization in the test procedure used to determine these miscellaneous properties, and the general impracticability of making direct comparisons of the results obtained by different investigators, much useful information on these properties can be obtained by any tests that are intelligently planned and sufficiently comprehensive.

THE PRINCIPAL WOOD PRESERVATIVES

William Chapman in his "Treatise on the Preservation of Timber," published in London in 1817, states:

> Almost every chemical principle or compound of any plausibility has been suggested in the course of the last five years, and submitted either to the admiralty or navy boards; but the multiplicity and contradiction of opinions formed nearly an inextricable labyrinth.

In the century and more that has elapsed since Chapman's time, an untold number of substances have been proposed as wood preservatives. These include practically all known chemicals of moderate cost as well as industrial by-products and waste products of every description. Fortunately, however, considerable progress has been made in charting the "inextricable labyrinth," and the intervening years of experience and study have brought due recognition to those few chemicals that are economical, effective, and otherwise acceptable for commercial use. The great majority of the suggested preservatives have proved to be insufficiently effective or otherwise impractical, if not utterly useless.

Preservatives may be grouped into three general classes, *viz.*, (*a*) preservative oils, or mixtures of oils, that are of low volatility and only slightly soluble in water; (*b*) inorganic salts and similar materials that are used in water solution; and (*c*) toxic chemicals that are dissolved in some colorless and usually volatile solvent other than water.

PRESERVATIVE OILS

The preservative oils that are in more or less common use include coal-tar creosote, anthracene oils or carbolineums, water-gas-tar creosote, wood-tar creosote, coal tar, water-gas tar, and solutions of creosote in petroleum or tar.

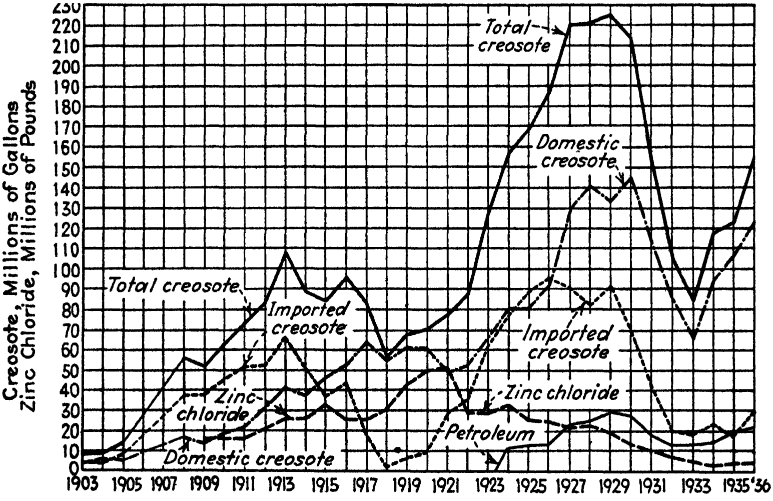

FIG. 26.—Annual consumption of coal-tar creosote, petroleum, and zinc chloride for wood-preserving purposes, 1903–1936. Figures are not available for creosote for 1906 and 1907 or for zinc chloride prior to 1909. (*U.S. Forest Service.*)

Coal-tar Creosote.—During most of the hundred years since John Bethell patented the use of "dead oil of tar" for wood treatment (Brit. pat. 7731, July, 1838), coal-tar creosote has been regarded as the standard preservative. It is the most effective chemical known for the protection of wood against decay, insects, and marine borers and is now in general use throughout the world. The amounts of creosote used annually in the United States since 1903 are shown in Fig. 26. It will be noted that considerable quantities are imported to supplement the domestic supply, which apparently has never been adequate.

Coal-tar creosote is defined by the American Wood-Preservers' Association (1) as follows:

> *Creosote or Creosote Oil.*—As used in wood preserving, creosote is a distillate of coal tar produced by high temperature carbonization of bituminous coal; it consists principally of liquid and solid aromatic hydrocarbons and contains appreciable quantities of tar acids and tar bases; it is heavier than water; and has a continuous boiling range of at least 125 degrees C., beginning at about 200 degrees C.

In the distillation of coal tar, the first fractions obtained contain the so-called *light oils,* and the residue left after the completion of the process is pitch. The higher boiling, liquid fraction, recovered between these two general classes of material, is designated as creosote. The character of the tar, the details of the distillation process, and the proportion of the distillate included in the creosote fraction all influence the character of the creosote itself. Coal-tar creosote is not a single chemical substance but rather a mixture containing a great number of compounds, many of which are used commercially. To meet the market demands, individual components may be removed from the creosote, which is essentially a by-product. Thus, the character of the coal-tar creosotes available to the wood-preserving industry varies considerably (4). Moderate differences in composition do not prevent these preservative oils from giving good service, however, and satisfactory effectiveness may be expected from any coal-tar creosote that does not differ greatly from the normal.

A complete list of the individual chemical compounds found in coal-tar creosote would be very difficult to prepare and would probably include several hundred names. The known constituents may be grouped into three principal classes, *viz.*, the *tar acids,* the *tar bases,* and the *hydrocarbons* (4). A few additional compounds, occurring in very small amounts and mainly sulphur containing, do not fall into these groups, but they are not believed to be of importance for wood preserving.

The tar acids, which are not true acids in the chemical sense, usually comprise less than 5 per cent of a normal creosote. They include various phenols, cresols, xylenols, and naphthols, all of which are toxic to wood-destroying fungi and other organisms.

The tar bases include the pyridines, quinolines, and acridines, most of which are toxic. The amount of these substances in a normal creosote probably does not exceed that of the tar acids.

The hydrocarbons, which make up most of the volume of creosote, include benzene, toluene, xylene, naphthalene, acenaphthene, phenanthrene, anthracene, and fluorene. The first three of these chemicals are very low-boiling and properly belong in the *light-oil fraction*, but the distillation process does not exclude them entirely from the commercial creosote (4). In the creosotes produced 30 years ago or more, naphthalene was without doubt the predominating hydrocarbon and at times constituted as much as 50 per cent of the total oil. In modern creosotes, the so-called *naphthalene fraction* (obtained below 235°C.) is restricted by specification (1) to not more than 25 per cent, of which perhaps half may be naphthalene. The higher boiling hydrocarbons (above 235°C.), such as fluorene, anthracene, and phenanthrene, predominate in many of the present-day creosotes.

The mixture of hydrocarbons that distills between 200 and 275°C. is more toxic to wood-destroying fungi than the whole creosote. A number of the individual hydrocarbons found within this boiling range are extremely toxic, while others are not quite soluble enough to exert their full poisonous effect, although they retard the growth of fungi very markedly. The mixture of hydrocarbons distilling above 275°C. is practically nontoxic, the individual oils beng too insoluble in water to have any poisonous effect. However, they are important constituents in the creosote, since they act collectively as a carrier or reservoir for the tar acids, the tar bases, and the lower boiling hydrocarbons, giving up these toxicants very slowly to the water in the treated wood.

Specifications for coal-tar creosote do not name the various chemical compounds or designate the proportions of each that the oil should contain. Instead, they stipulate that the oil shall be a derivative of coal tar, provide definite restrictions as to its specific gravity and distillation range, and carefully limit the amounts of undesirable impurities it may contain. The requirements of the following standard specification of the American Wood-Preservers' Association (1) are the same as those of the American Railway Engineering Association, the United States government, and various industrial concerns.

Preservatives meeting these requirements give generally satisfactory results. Practically all creosote producers can meet this specification without difficulty.

CREOSOTE FOR TIES AND STRUCTURAL TIMBERS

(Grade 1)

1. The creosote shall be a distillate of coal-gas tar or coke-oven tar.* It shall comply with the following requirements:

2. It shall not contain more than 3 per cent of water.

3. It shall not contain more than 0.5 per cent of matter insoluble in benzol.†

4. The specific gravity of the creosote at 38°C., compared with water at 15.5°C., shall be not less than 1.03.

5. The distillate, on a water-free basis, shall be within the following limits:

Up to 210°C., not more than 5 per cent.
Up to 235°C., not more than 25 per cent.

6. The creosote shall yield not more than 2 per cent of coke residue.

7. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL—Creosote, Analysis.)

This specification does not limit the amount of residue above 355°C., although creosotes containing high residues generally have higher viscosities, lower toxicities, and greater tendency to bleed from the wood than those having moderate or low residues. Some important purchasers, therefore, add a special requirement to the specification, limiting the amount of residue above 355°C. to a definite maximum, such as 20 or 25 per cent. The requirement can be met without difficulty by either domestic or imported creosotes, although probably more easily by the latter. This limitation of residue is especially desirable if the coal-tar creosote is to be mixed with petroleum oil or any other oil having little or no toxicity. Further assurance of adequate toxicity might be obtained by placing a minimum limit on the amount of oil distilling below 275°C., for Bateman (4) has shown that the toxicity of a given creosote is closely related to the percentage of this fraction (Fig. 27). The percentage to be specified would have to be very carefully considered, however, in order to avoid an impractical requirement.

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* Owing to the complexity of the chemical composition and physical properties of coal-tar creosote, and to the fact that some of the same compounds and properties which characterize coal-tar creosote are found in certain petroleum derivatives, the determination of the purity of creosote is difficult. When there is not certain assurance that the oil is a pure product, the following tests will aid in arriving at an opinion as to its coal-tar origin: (*A*) Fraction distilling between 210° and 235°C. is usually solid or contains some solids when cooled to 25°C. (*B*) All of the fractions up to 315°C. contain tar acids in varying amounts, usually at least 1 per cent, calculated on the amount of the fraction tested. (See MANUAL—Creosote, Analysis, Tar Acids.) (*C*) The specific gravity of the fraction between 235° and 315°C. is usually not lower than 1.025, and the specific gravity of the fraction between 315° and 355°C. is usually not lower than 1.085 at 38°C., compared with water at 15.5°C. However, some pure coal-tar distillates fall slightly below these limits. If the sample does not comply with at least one of the foregoing tests, it is undoubtedly not a pure coal-tar creosote.

† Samples of creosote taken from working tanks may show an increase in matter insoluble in benzol, due to treating operations. Such increases, provided they do not exceed by 1 per cent the specification limits, should not serve to cause rejection of the creosote for non-conformity with specifications, if it can be shown that the original fresh oil was of specified quality.

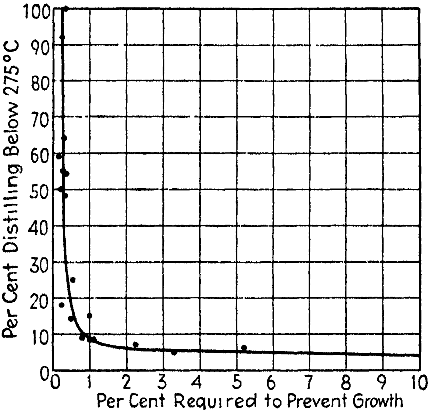

FIG. 27.—Relation between percentage of coal-tar creosote distilling below 275°C. and toxicity of the preservative to the fungus "Madison No. 517." (*U.S. Forest Products Laboratory.*)

In comparing different creosotes with each other, or in checking them against a given specification, it is necessary to follow exactly the same analytical procedure in each case. Otherwise, the results will not be comparable. Complete specifications covering the various details in the analysis of creosote have been adopted (up to 1937) by the American Wood-Preservers' Association (1) as follows:

	Specification Number
Distillation	11e
Specific gravity of creosote	18c
Specific gravity of fractions	9c
Amount of water	10d
Matter insoluble in benzol	8b
Coke residue	7d
Determination of tar acids	26a
Sampling from tank cars	25b

The principal advantages of coal-tar creosote as a wood preservative are (*a*) its marked toxicity to wood-destroying fungi, marine borers, and insects; (*b*) its relative insolubility in water and low volatility, to which the oil owes its high degree of permanence under the most varied service conditions; (*c*) its ease of application; (*d*) the facility with which its depth of penetration can be determined; and (*e*) its general availability and relatively low cost.

While it is the best available preservative for treating structural timbers intended for general outdoor service, coal-tar creosote has certain properties that are undesirable when the treated wood is to be used for some special purposes. Freshly creosoted timber can be ignited easily and will burn readily, producing a dense smoke, although after the treated wood has seasoned for some months its ease of ignition is very decidedly lessened. (See discussion of inflammability of treated wood, page 312.) The use of creosoted wood is sometimes objected to because of the odor of the preservative. However, there is generally no noticeable odor when creosoted lumber is employed in houses for sills and foundation timbers, floor joists, floor sleepers embedded in or resting on concrete, and even subflooring (24). On the other hand, foodstuffs sensitive to odors should not be stored near creosoted material. Workmen sometimes object to handling the treated wood, as the preservative soils their clothes and, in some cases, may burn the skin of the face and hands, causing an injury similar to sunburn. Creosoted timber has no other apparent effect on the health of people working with or near it, nor is it in any way injurious to the occupants of buildings in which such treated material has been used. With regard to the health factor, it may be pointed out that creosoted wood-stave pipe is successfully used in some localities for conducting drinking water to cities. The dark color of creosote and the fact that it usually cannot be painted over satisfactorily make it unsuitable for finish lumber or other forms of wood in which appearance and paint receptivity are of major importance. (See page 315 for discussion of the painting of creosoted wood.)

Liquid coal-tar creosote, or *liquid creosote*, is the name applied to coal-tar creosote so modified, by the extraction of part of the chemical compounds that crystallize at ordinary temperatures, as to produce a completely liquid oil at moderate atmospheric temperatures. This makes it possible to apply the unheated preservative successfully by brushing, spraying, or dipping, except during cold weather. However, even liquid creosote should be heated whenever possible, in order to facilitate its penetration into the wood. Preservatives of this type can also be easily removed from shipping containers without preliminary warming and in this respect may have a distinct advantage over ordinary coal-tar creosote. The latter generally contains a considerable proportion of solids even at moderate atmospheric temperatures, and these would be left in the container if not redissolved by heating. There is no reason to believe that liquid creosotes have better preservative value than ordinary creosotes, but they often are more convenient to handle.

The following specification of the American Wood-Preservers' Association (1) is for a liquid creosote intended for brush, spray, or open-tank treatments. This preservative is required to be of higher specific gravity than the ordinary creosote used in pressure treatments. Such a stipulation is made for a twofold purpose: (*a*) to reduce evaporation losses when the preservative is heated in open vessels and (*b*) to meet the wishes of those who believe that, because an increase in specific gravity reduces volatility, high-gravity creosote oils are better preservatives than those of lower gravity. The correctness of the latter belief is not accepted by all investigators.

CREOSOTE FOR BRUSH OR SPRAY TREATMENT

1. The creosote shall be a pure distillate of coal-gas tar or coke-oven tar.* It shall comply with the following requirements:
2. It shall be fluid at 15°C. and crystal free at 38°C.
3. It shall not contain more than 1 per cent of water.

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* See first footnote on page 103.

4. It shall not contain more than 0.5 per cent of matter insoluble in benzol.

5. The specific gravity of the creosote at 38°C., compared with water at 15.5°C., shall not be less than 1.06.

6. The distillate, on a water-free basis, shall be within the following limits:

Up to 210°C., not more than 1 per cent.
Up to 235°C., not more than 10 per cent.
Up to 355°C., not less than 65 per cent.

7. The creosote shall yield not more than 2 per cent coke residue.

8. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL—Creosote, Analysis.)

Anthracene oils, or *carbolineums*, as they are commonly known, are coal-tar distillates of higher specific gravity and higher boiling range than ordinary coal-tar creosote or liquid creosote. They usually have enough of the solids (chiefly anthracene and phenanthrene) removed to make the oils liquid at moderate atmospheric temperatures. On account of their higher gravity and boiling range, these oils are less toxic to fungi and less volatile than ordinary creosotes. Otherwise, their general properties and their effectiveness as preservatives are similar to those of coal-tar creosotes. They are used principally for brush, spray, and open-tank treatments. The following specification of the American Wood-Preservers' Association (1) describes the general properties of "liquid" anthracene oils, or carbolineums.

ANTHRACENE OIL

1. The oil shall be a distillate of coal-gas tar or coke-oven tar.* It shall comply with the following requirements:

2. It shall be fluid at 15°C. and shall remain crystal free at 38°C.

3. The specific gravity of the oil at 38°C., compared with water at 15.5°C., shall not be less than 1.09 nor more than 1.13.

4. It shall not contain more than 0.5 per cent of water.

5. It shall not contain more than 0.5 per cent of matter insoluble in benzol.

6. The distillate, based on water-free oil, shall be within the following limits:

Up to 235°C., not more than 1.5 per cent.
Up to 300°C., not more than 16.5 per cent.
Up to 355°C., not less than 45 per cent.

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* See first footnote on page 103.

7. The oil shall yield not more than 2 per cent coke residue.
8. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL —Creosote, Analysis.)

Water-gas-tar Creosote.—This creosote is derived from water-gas tar, which is the residue remaining from the carburetion of water gas with petroleum oil. In the process that results in the formation of water-gas tar, the petroleum is subjected to approximately the same degree of heat as is used in producing high-temperature coal tar from bituminous coal. The hydrocarbons found in water-gas tar are chiefly aromatic and, in general, are similar to, if not identical with, many of the hydrocarbons found in coal tar. Like coal tar, the petroleum product may or may not contain aliphatic hydrocarbons. The water-gas-tar creosote is distilled from the tar in much the same way that coal-tar creosote is made from coal tar. The composition of the water-gas tar, as well as that of the creosote made from it, will vary with the character of the petroleum used and especially with the conditions under which the tar is produced. Water-gas-tar creosotes differ from the coal-tar oils mainly in having practically no tar acids or tar bases and thus are more or less comparable to coal-tar preservatives from which these ingredients have been removed (4).

Water-gas-tar creosotes cannot be distinguished with certainty from coal-tar creosotes by any known chemical or physical tests. If a creosote contains no tar acids or tar bases, it is probably a water-gas-tar product, although it may possibly be a coal-tar derivative from which these substances have been extracted. On the other hand, the presence of tar acids and bases is no assurance that the creosote is a pure coal-tar product, since it may be a mixture of water-gas-tar and coal-tar oils. The tests described in the first footnote on page 103 give a reasonable indication, but not absolute proof, of origin.

The toxicity of water-gas-tar creosotes, like that of the coal-tar preservatives, varies with the percentage of distillate obtained below 275°C. (4), when the American Wood-Preservers' Association standard method of distillation (1) is used. Creosotes having a high percentage distilling below 275°C. are more toxic than those with a relatively low percentage. Water-gas-tar creosotes have generally lower, and sometimes very much lower, toxicities than those derived from coal tar. As a rule, however, they are toxic enough to be very good preservatives.

Water-gas-tar creosotes are not often sold as such for wood-preserving purposes, but they are probably mixed to some extent with coal-tar creosotes, either by blending the two types of preservative directly or by combining the original tars before distillation. If attention is paid to obtaining a product of suitable characteristics, either water-gas-tar creosote or its mixtures with coal-tar creosote can be used very effectively for wood preservation.

No standard specification for water-gas-tar creosote, to be used alone in the treatment of ties and structural timber, has been accepted by any recognized organization in this country. However, the following specification, covering such preservative for use with zinc chloride (in the Card process), has been adopted by the American Wood-Preservers' Association (1):

WATER-GAS-TAR DISTILLATE FOR USE WITH ZINC CHLORIDE

1. The oil shall be a distillate of water-gas tar which shall comply with the following requirements:

2. It shall not contain more than 3 per cent of water.

3. It shall not contain more than 0.5 per cent of matter insoluble in benzol.*

4. The specific gravity of the oil at 38°C., compared with water at 15.5°C., shall not be less than 1.02.

5. The distillate, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5 per cent.
Up to 235°C., not more than 25 per cent.
Up to 355°C., not less than 70 per cent.

6. The oil shall not yield more than 2 per cent of coke residue.

7. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL —Creosote, Analysis.)

This specification limits the residue above 355°C. to not more than 30 per cent and thus guards against the inclusion of excessive amounts of high-boiling oils of low toxicity. Further protection in this respect could be obtained by providing a suitable minimum for the amount of oil distilling below 275°C., but care would have to be taken to avoid making an impractical requirement.

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* See second footnote on page 103.

The advantages and disadvantages of water-gas-tar creosote for treating various forms of timber are generally similar to those of coal-tar creosote.

Wood-tar Creosote.—This oil is made by distilling the wood tar that is produced as a by-product in the destructive distillation of either hardwoods or softwoods. As with creosotes obtained from other sources, the properties of this type of preservative will depend upon the character of the tar used, and the details of the distilling process. Any subsequent refinement of the oil itself will also affect the quality of the creosote. Hardwood tar is produced in greater volume than softwood tar and is also more generally distilled into light oils, creosote, and pitch. Much of the pine tar, which is practically the only softwood tar produced, is used without further refinement in the manufacture of cordage.

Wood-tar creosotes have not been extensively used for preserving wood, chiefly because the quantities available have been too small to interest large consumers of creosote. The quality of these oils has also been quite variable, and only a few of them have been produced to conform to a specification. Although some hardwood-tar creosotes are carefully manufactured and refined, with a view to producing a product of high quality, many of those sold for wood-preserving purposes are merely by-product oils and tar residues of miscellaneous character which cannot be marketed advantageously for other purposes at the moment. This latter characterization is especially true of wood-preserving oils derived from softwoods. No standard specification for wood-tar creosote has been accepted by the American Wood-Preservers' Association or any other similar organization of creosote users. However, the following specification was adopted in 1928 by the National Wood Chemical Association, the members of which are manufacturers of wood-tar creosote:

HARDWOOD CREOSOTE OIL (No. 1)

1. The specific gravity of the oil at 20°C. shall be not less than 1.06.
2. When the oil is distilled by the standard method used by the American Wood-Preservers' Association for wood preservatives, the following distillate shall be obtained:

a. Not more than 4 per cent at 200°C., of which not more than 2 per cent shall be water.
b. Not more than 40 per cent at 225°C.
c. Not less than 85 per cent at 270°C.

3. The fraction distilling between 200° and 225°C. shall have at least 30 per cent of its volume soluble in 10 per cent caustic soda.
4. Water, from washing the oil with an equal volume of water, shall be less than 0.5 per cent acid, calculated as acetic.

There is undoubtedly room for much improvement in the foregoing specification, but it serves as a good starting point for the development of acceptable standards of quality. Hardwood-tar creosotes that conform to it will undoubtedly have high toxicity and will add materially to the life of wood that is adequately impregnated. Whether they are as good as coal-tar creosotes is not known, however, because service records on timber treated with the wood-tar derivatives are not available in sufficient quantity to permit accurate comparison.

Hardwood tars are decidedly acid in character. Consequently, unless special precautions are taken during the distillation and subsequent refining processes, the creosotes made from them may also have a high acid content. This is a distinctly objectionable feature, since these acids, which are chiefly acetic and formic, are definitely corrosive to iron and steel and, therefore, make the preservatives unsuitable for use in commercial treating equipment. These are not to be confused with the so-called "tar acids" that occur in coal-tar creosote and also to a limited extent in the wood-tar product. The latter are not true acids in a chemical sense but are phenols and hence not corrosive to iron and steel. Wood-tar creosotes cannot be considered suitable for use in wood-preserving plants, unless their "true-acid" content is kept as low as practicable.

Creosote Emulsions.—Emulsions of coal-tar creosote or wood-tar creosote with water have been suggested (34) as a means of reducing the amount and cost of the creosote required when deep penetrations are desired. Although some success has apparently been attained in securing good emulsions that penetrate wood satisfactorily, and also do not separate on heating or long standing, such preservatives have not been used to any great extent. This may be due to the fact that the Rueping (empty-cell) method of treatment accomplishes the same purpose more simply and also that the advantages of the emulsions do not offset the extra cost and inconvenience of preparing and using them.

Coal Tar.—Until recently, this product was seldom used alone in the commercial treatment of timber, because it was generally too viscous and contained too many impurities to penetrate wood well. Its toxicity is also generally lower than that of coal-tar creosote. However, since toxicity is determined very largely by the proportion of the product that boils below 275°C., it is possible for coal tars to be at least as poisonous to wood-destroying fungi as the very high-boiling coal-tar creosotes. Some railroad companies are now using straight coal tar as a preservative for ties, but the general practicability and economy of the procedure remain to be demonstrated. Except in easily treated wood, penetrations are likely to be shallower than those obtained with creosote, and longer treating periods are required to obtain given absorptions of the preservative. The tar-treated ties may also be dirtier to handle. On the other hand, if the tar is of suitable quality, and if deep penetrations are obtained, very good protection should result. Since it is not known whether the tar-treated ties will last as long as ties impregnated with straight creosote or creosote solutions, it is not possible to calculate the probable economy with any approach to accuracy. The tar, of course, should be as free from water and solids and as low in viscosity as practicable.

Creosote-Coal-tar Solutions.—Since about 1908 (10), the practice of mixing coal tar with coal-tar creosote in proportions as high as 50 per cent has become quite common for the treatment of ties and certain other timbers. The tar is added primarily to reduce the cost of the preservative, but its presence probably also decreases the tendency of the treated wood to check or split in service. Tar solutions are more liable than straight creosote to cause "bleeding" (page 316) on the surface of treated wood. If the tars are clean and do not interfere seriously with penetration, these solutions make excellent preservatives.

The extract given below is taken from the American Wood-Preservers' Association standard specification for creosote-coal-tar solution for ties and structural timber (1). It approves the use of tar in amounts up to 20 per cent only, but some railroads and other consumers use much higher proportions. The

A.W.P.A. specification for coal-tar paving oil (1) permits up to 35 per cent of coal tar in mixture with coal-tar creosote.

CREOSOTE-COAL-TAR SOLUTION

1. The solution shall be a coal-tar product of which at least 80 per cent shall be a distillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar.* It shall comply with the following requirements:

2. It shall not contain more than 3 per cent of water.

3. It shall not contain more than 2 per cent of matter insoluble in benzol.†

4. The specific gravity of the solution at 38°C., compared with water at 15.5°C., shall be not less than 1.05 or more than 1.12.

5. The distillate, on a water-free basis, shall be within the following limits:

Up to 210°C., not more than 5 per cent.
Up to 235°C., not more than 25 per cent.

6. The solution shall yield not more than 6 per cent coke residue.

7. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL —Creosote, Analysis.)

Water-gas Tar.—This tar is not approved for mixing with creosote in the specifications of the American Wood-Preservers' Association, but it should give very good results when used in this way. Tar of this type contains less free carbon than does coal tar and in some cases can be made to penetrate well. Its toxicity is usually rather low, but if injected into wood to sufficient depth and in adequate quantity it would undoubtedly afford considerable protection, at least against decay.

Refined water-gas tar has been approved by the American Wood-Preservers' Association (1) for the treatment of wood paving blocks, provided that it meets the following specifications:

REFINED WATER-GAS TAR

1. The preservative shall be refined water-gas tar. It shall comply with the following requirements:

2. It shall contain not more than 3 per cent of water.

3. It shall contain not more than 2 per cent of matter insoluble in benzol and chloroform.

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* See first footnote on page 103.

† See second footnote on page 103.

4. The specific gravity of the preservative at 38°C., compared with water at 15.5°C., shall not be less than 1.11 nor more than 1.14.

5. The distillates, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5 per cent.
Up to 235°C., not more than 15 per cent.
Up to 315°C., not more than 40 per cent.
Up to 355°C., not less than 25 per cent.

6. The specific gravity of the total distillate below 355°C. shall not be less than 0.99 nor more than 1.02 at 38°C., compared with water at 15.5°C.

7. The foregoing tests shall be made in accordance with the standard methods of the American Wood-Preservers' Association. (See MANUAL—Creosote, Analysis.)

Petroleum Oils.—As a group, petroleum oils are not toxic to wood-destroying fungi and, therefore, are not suitable to use alone as wood preservatives. It should be possible by chemical processing, however, to form toxic compounds in petroleum oils, and this may be a commercial development of the future. Gas oils, which are petroleum products somewhat heavier than kerosene and lighter than lubricating oils, are nontoxic as a rule, but a few of them have been found to have slight toxicity. While crude petroleum, "topped" petroleum, fuel oil, gas oil, and waste crankcase oil have proved to be unsatisfactory as preservatives, they can, nevertheless, be used as cheap carriers for toxic chemicals or as diluents for coal-tar creosote.

Good preservatives can probably be made with petroleum oils by the addition of chemicals of high toxicity. This has been done experimentally at various times. In 1926, Wood (38) described an experimental preservative containing 3 per cent beta naphthol, 10 per cent pine oil, and 87 per cent gas oil, based on earlier work by Bateman (3). Test specimens treated with this mixture, and also with preservatives made by adding dinitrochlorbenzene, dinitronaphthalene, tetrachlorphenol, or carbazole to petroleum, were included in 1931 in the service test against termites and decay on Barro Colorado Island, C. Z., conducted by the Bureau of Entomology and Plant Quarantine and the Forest Products Laboratory of the U. S. Department of Agriculture (25). In 1934, the Forest Products Laboratory used 3 and 5 per cent solutions of tetrachlorphenol in waste automobile-crankcase oil for the treatment of experimental fence posts. Additional fence post experiments by the same laboratory, including both tetrachlorphenol and pentachlorphenol in petroleum, were started in 1936. The outcome of such experiments as these will indicate whether or not preservatives of this kind are promising enough to justify more extensive use.

Creosote-Petroleum Solutions.—Petroleum has been used as a diluent for coal-tar creosote since 1909, when the Atchison, Topeka, and Santa Fe Railway began to employ such solutions on a large scale in the treatment of crossties (10), and it is now being used for this purpose by many railways. The volume of petroleum consumed for wood-preserving purposes in the United States since 1923 is shown in Fig. 26. The proportion of petroleum in the solution varies with different companies, some railways using as much as 70 per cent, and others as low as 30 per cent of the diluent; the most common practice is to use about 50 per cent petroleum. The primary purpose in adding petroleum to creosote is to reduce the cost of the preservative. For example, by adding a gallon of fuel oil, costing 4 cts., to a gallon of creosote, priced at 12 cts., a mixture or solution costing 8 cts. per gallon is obtained; this effects a saving of one-third the price of the straight creosote. The cost reduction is dependent, of course, upon the prices of creosote and petroleum, which vary from time to time and in different parts of the country.

When injected into ties and other timbers that are exposed to the weather, creosote-petroleum solutions also have an advantage in that they reduce checking to a greater degree than straight creosote. The petroleum keeps the surface of the wood more oily than does the creosote and thus makes the timber less subject to rapid changes in moisture content, which favor checking.

The toxicity of creosote-petroleum solutions is reduced more than in direct proportion to the percentage of petroleum added (5). For this reason, coal-tar creosotes of high toxicity are best for such mixtures. Creosotes having a high percentage of residue above 355°C. are not so suitable, from the standpoint of toxicity, as those having 25 per cent or less above that temperature. Creosote-petroleum solutions usually have higher viscosities than straight creosote and, therefore, do not penetrate so readily. This difficulty can be overcome, however, by using suitable treating conditions.

No standard specification has been adopted for petroleum that is to be mixed with creosote. It has been recommended (10) that the petroleum should preferably be of an asphalt base, but mixed asphalt- and paraffin-base oils may be used if the amount of sediment that forms with the creosote is low. Some of the paraffin-base oils produce considerable sediment, or sludge, when combined with coal-tar creosote, so that it is advisable, before making up large quantities, to prepare a small test sample of a proposed mixture and observe the amount of sediment that forms. The sludge is undesirable because it makes the treated wood very dirty to handle; it also settles out in the bottoms of tanks and on steam coils, and is expensive and inconvenient to remove. The Committee on Preservatives of the American Wood-Preservers' Association suggested in 1937 that the specific gravity of the petroleum be not less than 0.96 at 60°F., compared to water at the same temperature, that the water and sediment be not more than 1 per cent, and that the flash point be not less than 215°F., as determined by the Pensky-Martens closed tester (35). No specific limit on viscosity was proposed.

PRESERVATIVES INJECTED IN WATER SOLUTIONS

A number of water-soluble salts are employed as wood preservatives. Zinc chloride is the outstanding chemical in this group, but chromated zinc chloride, sodium fluoride, mercuric chloride, and copper sulphate are also used as well as several proprietary preservatives.

Zinc Chloride.—This salt is the principal water-soluble preservative used in the United States (14). It is inexpensive, uniform in quality, and readily available in any quantity, and wood impregnated with it is clean, paintable, and slightly reduced in flammability. The chief disadvantage of the preservative is its ready solubility in water, which causes the salt to leach out of treated timber under wet exposure conditions. The water injected with the zinc chloride during impregnation temporarily adds to the weight of the wood and necessitates subsequent seasoning before the timber can be satisfactorily used for some purposes. Adequate drying is particularly essential when the treated wood is to be installed in structures in which the shrinkage that accompanies the reduction in the moisture content of the material would be objectionable.

The use of zinc chloride was recommended by Wade in 1815 (28) and patented in England in 1838 by William Burnett (Brit. pat. 7747), but it does not appear to have been employed to any great extent in Europe. Its most extensive application has been in the United States, where, between 1909 and 1921, the quantity used increased from 16 to 51 million pounds per year (21). During and immediately following the World War, when importations of coal-tar creosote from Europe were drastically curtailed, many former creosote users had to turn to zinc chloride. The annual consumption of this salt by the wood-preserving industry has been falling rather steadily since 1921, until it is now very much lower than in 1909 (Fig. 26). This decrease has been due, in part, to the increase in supply and the reduction in cost of creosote since 1921 and, in part, to the desire of the railways for greater protection to their crossties than can be obtained with zinc-chloride treatment. The increasing use of creosote-petroleum and creosote-tar solutions has been made partly at the expense of zinc chloride.

Zinc chloride is a primary product and not a by-product, being made by the action of hydrochloric acid on zinc. When the freight cost is not prohibitive, it is shipped in concentrated solutions, usually of 50 per cent but sometimes of higher strength. For long freight hauls it is transported in solid (fused) form in airtight containers, which are required because the solid zinc chloride is very deliquescent and quickly absorbs moisture when exposed to the air. Solutions of from 2 to 5 per cent strength are prepared from the concentrated material for use in treating wood. Despite the deliquescence of the salt, timber impregnated with the amounts of zinc chloride usually specified does not attract moisture or become damp to a noticeable degree.

For most outdoor uses zinc chloride gives less prolonged protection to timber than either coal-tar creosote or the commonly used solutions of creosote in tar or petroleum. This is apparently due to the fact that the salt leaches out of the wood under the action of rain and melting snow and of soil moisture. On the other hand, in locations where wood is not exposed to the leaching effect of water, as in buildings, zinc chloride gives practically permanent protection. The available service records have, as yet, disclosed no limit to the life of zinc-chloride-treated wood that has been installed in such locations. During recent years, this preservative has been used frequently in the treatment of roof planking, for factories in which high relative humidity favors rapid decay. It also is used for decay- and termite-protection in dwellings. The use of zinc-treated wood in such structures as these is furthered by the fact that the timber can be painted successfully. (See discussion of painting zinc-treated wood, page 316.)

Zinc chloride was formerly used quite extensively in treating ties by the Card method, which provided for impregnation with a mixture of zinc chloride solution and coal-tar creosote. The addition of the creosote made the ties last longer than when treated with zinc chloride alone, but the mixture did not give the wood so extended a life as straight creosote or creosote-tar or -petroleum solutions. Zinc chloride has also been used to some extent in two-movement treatments, in which ties were first impregnated with a solution of the salt and then treated with petroleum or creosote. In some cases, the ties were allowed to season between the injection of the zinc chloride and the oil; while in other instances, the salt solution was forced into the wood by an empty-cell process, and the oil injected immediately afterward. Although such treatments are less convenient than one-movement processes, the results appear to have been quite satisfactory.

The specification generally used in the purchase of zinc chloride for wood-preserving purposes is that of the American Wood-Preservers' Association (1), which states:

> The zinc chloride shall be acid free and shall not contain more than 0.1 per cent iron. Fused or solid zinc chloride shall contain at least 94 per cent chloride of zinc. Concentrated zinc chloride solution shall contain at least 50 per cent chloride of zinc.

Chromated Zinc Chloride.—This preservative contains about 80 to 82 per cent of zinc chloride, the remainder being sodium dichromate. It has been rather vigorously promoted since about 1934. Although developed by a manufacturer of zinc chloride and promoted mainly by one producer, it is not a patented formula but may be used by anyone without license. On the basis of laboratory studies and outdoor sapling tests, it is claimed that chromated zinc chloride is more resistant to leaching and gives more lasting protection than straight zinc chloride. The superiority is said to be sufficiently marked to justify using absorptions that are about ⅛ lb. less per cubic foot of wood than those recommended for zinc chloride, *e.g.*, ⅝ lb. of chromated zinc chloride, as compared with ¾ lb. of straight zinc chloride.

Chromated zinc chloride solution is injected into timber in the same manner as zinc chloride solution (except for the fact that it should not be heated to high temperatures) and contributes similar properties to the treated wood. Since it has come into commercial use so recently, insufficient time has elapsed to permit evaluation of this preservative on the basis of results obtained in actual service. Satisfactory results may be anticipated, but its superiority over straight zinc chloride remains to be proved by field experience.

Sodium Fluoride.—This preservative has been used experimentally since 1914 in treating railway ties and other timbers in the United States. It has also been employed to some extent commercially in the treatment of factory-roof timbers. In addition, sodium fluoride is an important ingredient in several proprietary or patented preservatives of European origin.

As indicated by laboratory tests, the toxicity of sodium fluoride to various wood-destroying fungi is quite similar to that of zinc chloride (Table IV). The available service records of treated wood used in contact with the ground also indicate a generally comparable serviceability of the two preservatives, although the zinc chloride may possibly be somewhat more effective in this type of exposure. Sodium fluoride is not suitable, however, for the treatment of wood that is to be placed in limestone ballast (39) or in contact with lime water, for it forms an insoluble, ineffective precipitate with calcium. For the same reason, water containing calcium salts in appreciable quantity is not so suitable as calcium-free water for preparing sodium fluoride solutions.

The advantages and disadvantages of sodium fluoride for wood treatment are, in general, similar to those of zinc chloride. Its solubility in water is much lower than that of zinc chloride, as evidenced by the fact that the maximum strength of solution obtainable at ordinary temperatures is about 4 per cent, but it appears to leach from wood in contact with the soil about as readily as does the zinc salt. Sodium fluoride is considered less safe to handle than zinc chloride because of its greater toxicity to man, its powdery form, and its resemblance to sodium bicarbonate and other chemicals used in foods. It also usually costs considerably more than zinc chloride. This latter factor is probably the chief reason why sodium fluoride has not been a more serious competitor of zinc chloride. Since it is not deliquescent, it can be shipped as a fine dry powder in bags or in slack cooperage. There is no standard specification for sodium fluoride for wood-preserving use, but the salt can be readily obtained in 95 to 98 per cent purity. Solution strengths of from 1½ to 3 per cent are commonly required for absorptions of ½ to ¾ lb. of dry salt per cubic foot of wood.

Mercuric Chloride.—Mercuric chloride (corrosive sublimate) is reported to have been employed for preserving wood as early as 1705 (28). Its use was first patented in England in 1832 by John Kyan (Brit. pat. 6,253), and the method of steeping wood in this preservative has consequently been termed *Kyanizing*, or the *Kyan process*. The first commercial treating plant in the United States, built at Lowell, Mass., in 1848, used this preservative in its earliest operations and at latest report was still doing so. Mercuric chloride is highly toxic to wood-destroying fungi but is expensive, corrosive to iron and steel, and a deadly poison. These disadvantages have greatly limited its use, and, since its corrosiveness makes it impractical to use the preservative in ordinary pressure equipment, it has been employed almost entirely for steeping or soaking lumber and timbers in open-tank equipment constructed of wood, concrete, or stone. In 1926, one treating plant in Germany was using pressure equipment in applying mercuric chloride, protecting the metal treating cylinder and pipes with corrosion-resistant paint and using wooden tracks and trams. In 1936, a pressure method of using mercuric chloride was reported from Czechoslovakia.

Despite the comparatively slight penetrations obtained with the process, Kyanized poles have given good service in Europe, and especially in Germany where they have been used in large numbers for many years. The average life of such poles in Germany has been variously estimated at from 14½ to 16½ years, in comparison with the approximately 23 years obtained there with creosoted poles (28). Kyanized poles are still used in

Europe, although not so extensively as in former years. In the United States, the use of mercuric chloride has been quite limited, but the results, so far as known, have been very good. The strength of the mercuric chloride solution employed in the Kyan process is usually about 1 per cent. During, or just prior to, the World War, an "improved Kyan process" was developed in Germany, in which a solution containing 0.67 per cent of mercuric chloride and 1 per cent of sodium fluoride was used.

Copper Sulphate.—Copper sulphate (blue vitriol), which was recommended for preserving wood as early as 1767 (11) and patented for that purpose in 1837 by Margary in England, is more toxic than zinc chloride to wood-destroying fungi. It has one major disadvantage in that it attacks iron and steel and, therefore, cannot be used in ordinary treating apparatus. One plant in France is reported as using it in regular pressure-treating equipment made of copper, but the preservative has found its widest use in the Boucherie process (page 216). The small amount of equipment required in this process can be made almost entirely of brass, copper, rubber, and wood, thus avoiding the use of iron or steel. Furthermore, this water-soluble salt is well adapted to the Boucherie process because the bluish color of the solution makes it easy to determine when treatment is complete.

Since copper sulphate can be precipitated out of solution by carbonates of calcium or magnesium, water containing these latter salts should not be used in preparing the preservative solution. Furthermore, the presence of such carbonates in ground waters has an unfavorable effect on the life of copper-sulphate-treated wood in lime-rich soil.

This preservative has never been employed extensively in the United States, but during the last few decades of the nineteenth century and the early years of the twentieth century it was used in Europe in the treatment of large numbers of poles by the Boucherie process. In Germany, these Boucherie-treated poles appear to have given nearly as long life as Kyanized poles and somewhat longer service than those impregnated with zinc chloride under pressure (28). In this comparison, the poles treated with copper sulphate had the advantage of complete sapwood penetration, while the others, and especially those that were Kyanized, had shallower penetrations. However, the popularity of the Boucherie process has declined in recent years, so that even in Europe the present annual consumption of copper sulphate for wood-preserving purposes is probably quite small. A government pole-treating plant in Denmark was using the Boucherie method in 1926, but its early abandonment was planned. The practice at that plant was to use a 1 per cent solution of copper sulphate which, with the spruce poles then being treated, gave an absorption of about 0.63 lb. of dry salt per cubic foot of wood.

Copper sulphate and other copper salts have been incorporated in numerous proprietary preservatives, several of which give promise of being very effective. However, none of them has been used to any great extent as yet.

Arsenic Salts.—Since the World War, arsenic salts, alone or in mixture with other substances, have found increasing use as wood preservatives, although mainly in patented formulas. Arsenic is toxic to many fungi, but, under conditions favorable to their growth, some can live in the presence of these salts and, according to certain investigators, even convert them slowly into poisonous gases (33). For this reason, there is more or less debate and disagreement over the advisability of allowing wood treated with arsenical preservatives to be used in inhabited buildings. Certain toxicologists maintain that even the very small amounts of arsenical gases that may be produced by fungi growing in damp, arsenic-treated wood in a building are hazardous to the health of the occupants of the structure. This claim is based on the fact that the poisonous effect of these gases is cumulative, and only small amounts are required to cause serious illness. This belief, obviously, is not shared by the promoters of arsenical preservatives, who consider that the hazard is insignificant. Some arsenical preservatives also contain other toxicants, not combined with the arsenic. Presumably these additional chemicals, if of high effectiveness, would prevent the growth of the arsenic-tolerant fungi. There is apparently no published evidence on this point, however. The question of the safety of arsenical salts is still unsettled, but it should be given consideration in connection with the proposed use of such preservatives in any place where there is insufficient ventilation to carry away the gases as rapidly as they may be formed.

Arsenic trioxide, brought into solution with a little caustic soda, has been used by the Anaconda Copper Mining Company at Rocker, Mont., in the pressure treatment of mine timbers and other forms of wood. Absorptions of about ½ lb. of dry salt per cubic foot of wood were obtained. No records on the serviceability of timber treated in this way have been made available to date.

By-product arsenic from the smelter at Anaconda, Mont , is the principal ingredient in Anaconda Wood Preservative, while arsenic compounds are important constituents of Chemonite, Tanalith, and Zinc-meta-arsenite. These four commercial proprietary compounds are discussed toward the close of this chapter under "Proprietary Preservatives."

TOXIC CHEMICALS IN TRANSPARENT ORGANIC SOLVENTS

Transparent, nonaqueous preservatives have been developed as the result of a demand for a practically colorless and odorless treatment, that can be applied to wood in finished dimensions without causing swelling, shrinking, or grain raising or interfering with the subsequent application of paint, varnish, or stain (22). These preservatives are in some demand for the treatment of window sash and frames, doors, flooring, interior partitions and finish, furniture, automobile-body parts, and similar articles. They are usually applied by dipping either heated or unheated wood into a tank of unheated preservative. Pressure impregnation is seldom, if ever, used with preservatives of this kind, mainly because of the high cost of the treating apparatus that would be required and the relatively heavy absorptions obtained in such treatments.

The solvent, in which the toxic chemical is dissolved, usually contains a very large proportion of a cheap, volatile, petroleum product of somewhat lower specific gravity than kerosene. Such a material is chosen mainly because it is less expensive than other volatile solvents that might be used. Pine oil is often added to assist in dissolving the toxicant and, in some cases, to mask its odor. High volatility is a desirable feature of the solvent, since it can then evaporate from the wood in a few days after treatment. As it evaporates, it leaves the toxicant in the wood, which is then in suitable condition for the application of finishes or for immediate use. Since the volatility of pine oil is not high, the percentage of this ingredient is kept low enough to avoid interference with prompt finishing or use. Nonvolatile drying oils, such as linseed oil, have occasionally been used in some formulas, in the belief that they would be effective as paint primers or waterproofers. However, their value for such purposes is probably slight and is discounted by the extent to which they interfere with penetration and with the application of stains to the wood.

The toxicant may be any chemical that is capable of being dissolved in the solvent to be employed, reasonably low in cost, sufficiently permanent, highly poisonous to fungi, and free from objectionable color, odor, or handling hazard. The studies of Bateman and his associates at the U.S. Forest Products Laboratory have provided the basis for the development of numerous toxicants of this character, of which the following, now in use or available for use in proprietary preservatives, are examples: beta naphthol, chlorbetanaphthol, tetrachlorphenol, pentachlorphenol, and chlororthophenylphenol. Preservatives of this type are commonly sold in concentrated solutions, which are diluted with a suitable solvent just before use, to a strength of about 5 per cent of the toxicant.

These preservatives are of such recent origin that adequate records of their performance under service conditions have not been accumulated. Since no other recognized preservatives answer the special purpose for which these new materials are intended, they must often be used largely on faith. However, it is reasonable to expect good results, if the toxicant and the solvent are well chosen, if there is sufficient toxicant in the solution, and if the treating is carefully and thoroughly done. The laboratory studies of Hubert (22) indicate that some of these preservatives are very promising.

The cleanness and rapid drying of these preservatives and the slight net increase in weight of the treated wood are properties that would often be advantageous in the treatment of poles, lumber, and structural timbers. However, the lack of conclusive service records, the relatively high cost, and the inflammable nature of the solvents used are disadvantages that prevent their large-scale use in treating such material at the present time.

PROPRIETARY PRESERVATIVES

Included in this category are preservatives of all types that are patented or sold under trade names. In fact, most preservatives in general use today were originally proprietary. Even coal-tar creosote, zinc chloride, mercuric chloride, and copper sulphate were covered by patents during the early years of their use; but since these grants expired so long ago, we do not now consider the chemicals as proprietary. Long lists of patents on preservatives and preserving processes will be found in the *Proceedings of the American Wood-Preservers' Association* for the years 1915, 1916, and 1935.

Manufacturers or promoters of unpatented proprietary preservatives usually do not like to disclose the composition of their products. This is quite natural, since disclosure of a formula in which much labor and expense have been invested might invite competition and result in considerable monetary loss. Furthermore, some of the formulas, if revealed, would prove to be unpatentable and easily duplicated, while others would be found to consist of cheap materials sold at high prices. If the formula is not disclosed, it is easy for the manufacturer to alter it from time to time, according to market conditions, without changing the name of the preservative and without the knowledge of the consumer.

The consumer should know just what he is buying. It is unwise for him to trust the life of his wood structures to preservatives of unknown composition or to invest his money in materials that may differ widely in quality from time to time without his knowledge. He is very likely to pay exorbitant prices for cheap, ineffective, or inferior materials. Before investing any appreciable amount of money, the consumer should insist, therefore, upon knowing the precise composition of the preservative he plans to buy. When convenient, it is also wise for him to make analyses to see that the material furnished complies with the stated formula or specifications.

The literature advertising some of the proprietary preservatives commonly contains extravagant claims as to their properties and effectiveness. Among the most misleading statements are those that influence the reader to believe that a mere brush application with the promoter's product will give adequate protection to wood. All advertising claims should be scrutinized carefully, checked against known facts, and discounted accordingly.

Ordinary liquid coal-tar creosotes and anthracene oils, though no longer patentable, are frequently sold under trade names or brands. The value of these products for preventing decay is similar to that of nonproprietary coal-tar creosote of comparable grade.

Some proprietary preservatives are by-products of the destructive distillation of wood. Those derived from hardwood tar are usually redistilled products and of the general character of the creosote covered in the specification given on page 110. Preservatives of this type undoubtedly possess a considerable degree of effectiveness in preventing decay. On the other hand, the miscellaneous by-product oils obtained in softwood distillation differ considerably in their properties and, probably, also in their effectiveness. There is little or no evidence of the preservative value of the softwood-tar creosotes.

A number of proprietary preservatives are included in the "fluoride-phenol" group, so called because the compounds included in it contain considerable quantities of sodium fluoride and either dinitrophenol or one of its salts. A chromate or bichromate is usually added to these mixtures to counteract the corrosive effect of the dinitrophenol as well as to increase the toxicity and permanence (resistance to leaching) of the preservative. In some cases, an arsenic compound is also added, to provide special protection against insect attack. As a rule, the fluoride-phenol preservatives are highly toxic and, if not used too sparingly, will be quite effective in preventing decay and insect damage. It has not been possible, as yet, to obtain sufficient service records on wood treated with these preservatives to permit a very definite evaluation of their effectiveness, as compared with that of zinc chloride or coal-tar creosote.

The number of proprietary preservatives on the market is so great and so constantly changing that it is impractical to prepare a complete list. The compounds discussed in the following paragraphs are among those that are receiving more or less attention at the present time and whose essential ingredients have been disclosed.

Ac-zol.—This compound is said to be prepared from copper sulphate (or oxide), zinc oxide, phenol, and ammonia; U.S. patent 959,505, issued May 31, 1910, however, covers only the use of copper salts, zinc salts, and ammonia. The preservative was originated in Belgium but is also manufactured in the United States. Ac-zol is sold in the form of a concentrated solution, reputed to contain about 12.5 per cent of total solids, and is diluted for use in the proportion of about 6 gal. of concentrated solution to 94 gal. of water. The diluted solution, therefore, contains slightly less than 1 per cent of total solids.

Ac-zol-treated timber has given good results in some installations, but it has not had extensive commercial use in the United States. The available service records are not sufficient to indicate the degree of protection that may reasonably be expected from this preservative.

Anaconda Wood Preservative.—This is a paste made from the dust that is precipitated by the Cottrell electrical process from the smoke and fumes in the smelter stack of the Anaconda Copper Mining Company at Anaconda, Mont. The dry form, in which it was originally marketed, was sometimes designated as "cold treater dust." The material varies somewhat in composition, according to the character of the ore being treated, but generally contains from about 75 to 80 per cent of arsenic oxides, chiefly the trioxide. The remainder consists of a great variety of metals or metallic compounds in small amounts, even including very minute amounts of gold and silver.

This preservative is used to some extent in the treatment of poles and posts. It was originally sold only in the form of dry powder or granules but is now furnished mainly in paste form (page 195). Some favorable and some unfavorable results have been reported. Animals should be kept away from the preservative in the soil, as they may swallow enough arsenic to cause their death.

Ascu.—British patent 404,855, issued in 1934 to S. Kamesam of Dehra Dun, India, covers the use of a solution containing copper, arsenic, and chromium salts in proportions claimed to be very resistant to leaching. According to the patent, the chromium should constitute between 45 and 90 per cent of the total chromium, copper, and arsenic present as elements, the copper between 8 and 40 per cent, and the arsenic between 8 and 50 per cent. A typical solution is reported to contain 1 part $As_2O_5 \cdot 2H_2O$, 3 parts $CuSO_4 \cdot 5H_2O$, and 4.5 parts $K_2Cr_2O_7$ in from 100 to 200 parts water by weight. Service records are not yet available for this preservative.

Basilit.—This is a fluoride-phenol preservative. A few years ago, it was composed of about 89 per cent sodium fluoride and 11 per cent dinitrophenolanilin. Subsequently, small percentages of other materials were added, but the proportion of sodium fluoride was not greatly changed. The use of Basilit has been confined mainly to Germany, where it is manufactured, and to other parts of Central Europe. It has found very little use in the United States. Available service data on ties treated with the old formula indicate that this preservative is moderately effective in retarding decay.

Bruce Preservative.—This product consists essentially of about 5 per cent of a toxic chemical, beta naphthol, in an organic solvent. When clean treatment is required, as in window sash, a colorless volatile carrier, such as Stoddard solvent, is used. If a dark color is desired, so that treated wood may be clearly distinguished from untreated material, an asphalt may be added. This type of preservative has been used to some extent in the treatment of automobile-body parts. If the treated wood is not required to be clean, a heavy petroleum product may be used as a carrier. Beta naphthol is known to be highly toxic to wood-destroying fungi. Bruce preservative has been in use only a few years, however, and has not had time to demonstrate its value by service records, except in the treatment of automobile-body parts where only a relatively short increase in life is required. In this type of service, the preservative has been reported by users to be entirely successful.

Carbolineums.—The name carbolineum is said to have been first applied to anthracene oils by Avenarius in Germany about 1875. He recommended a chlorinated anthracene oil, which was sold under the name of *Carbolineum Avenarius.* There is no indication, however, that the effectiveness of the preservative was definitely improved by the chlorination. Carbolineums, or anthracene oils, are now sold under numerous trade names in the United States and other countries. They are generally similar to coal-tar creosote in preservative effectiveness, though often claimed to be greatly superior.

Celcure (Celcure-Sol).—This preservative is available in both liquid and dry form. The original patents, U.S. 1,684,222 (1928) and Brit. 273,007 (1926) and 286,892 (1927), all granted to Gilbert Gunn of Scotland, applied to the use of "a slightly acid aqueous solution of a soluble chromate and a soluble copper salt." A more recent patent, U.S. 2,041,655 (1936), covers formulas for the preservative in dry form. A typical solution is composed of 5.6 per cent potassium dichromate, 5.6 per cent copper sulphate, 0.25 per cent acetic acid, and 88.55 per cent water. This solution is claimed to deposit insoluble toxic compounds in the wood when the treated material is seasoned or steamed. The small amount of test data and service information available indicate that Celcure has considerable value in protecting wood against termites and decay, but insufficient time has elapsed to permit comparison with other preservatives. The patent claims as to its effectiveness against marine borers are still under test. The preservative is being sold to some extent for brush or dip application, a practice that cannot be recommended.

Chemonite.—This preservative, developed by Dr. Aaron Gordon, is said to consist of copper arsenite (Scheele's green), with a small excess of copper hydroxide, in a strongly ammoniacal solution. The ammonia serves to prevent the corrosion of the iron in the treating apparatus by the copper in the preservative solution. It also delays the precipitation of the copper arsenite until the treatment has been completed and the ammonia has evaporated from the wood. It is claimed that the precipitate thus formed is practically nonleachable and that the treated wood may even be used successfully in salt water in the presence of marine borers. Modifications of the basic formula are recommended for special requirements, including fire resistance. Some favorable results have been obtained in posts and poles, but service records and laboratory data are as yet inadequate to show the extent to which Chemonite will satisfy the claims made for it.

No-D-K.—This is a hardwood-tar creosote, which is said by its manufacturers to comply with all the requirements of the specification for hardwood creosote oil No. 1 given on page 110. (See previous remarks as to the effectiveness of hardwood-tar creosotes.)

Par-tox.—Par-tox is a "clean," nonswelling preservative which is recommended for treating window sash and similar products. It is reported to consist essentially of the highly toxic 2-chlororthophenylphenol, dissolved in volatile solvents. No service records are available.

Permatol.—This is a trade name adopted by the Western Pine Association to cover certain preservative formulas of the transparent, nonaqueous type (page 123). The first formula published under this name (22) was as follows:

PERMATOL A

Pentachlorphenol	5 lb.
Pine oil or other solvents	1 gal.
Spreader*	1¼ gal.
Penetrant*	10¾ gal.

In PERMATOL B, half of the pentachlorphenol is replaced by tetrachlorphenol; in PERMATOL C, which is recommended for use where termites are active, all of the pentachlorphenol is replaced by tetrachlorphenol; and in PERMATOL D, 2-chlororthophenylphenol is the toxicant. Probably the toxicants and the proportions of the liquid constituents will be modified as experience is gained under actual working conditions. The name Permatol has been copyrighted and may be used only by permission, but the formulas are apparently not patented.

While service records on wood treated with Permatol are not available, it is reasonable to expect good results from the preceding formulas, if the wood is well penetrated.

Termiteol.—This is said to be a product obtained in the destructive distillation of southern yellow pine. Apparently it is a fraction of the oils obtained from the original distillation process and is not produced by the redistillation of wood tar. The available service records are too meager to indicate the extent of its effectiveness.

Toxicol.—Toxicol is a "clean," nonswelling preservative intended for treating window sash and similar products. It contains 2-chlororthophenylphenol or pentachlorphenol, both of which are highly toxic, dissolved in volatile solvents. No service records are available.

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* The term *spreader*, as used here, means refined kerosene or similar products; *penetrant* means Stoddard solvent and other solvents of similar character.

Wolman Salts.—The term Wolman salts is applied to a group of preservatives that have been developed by Dr. K. H. Wolman of Germany. They are all essentially fluoride-phenol mixtures but vary considerably in composition. The several salts are said to have had substantially the following composition when originally introduced into the United States, about 1921 or 1922:

TRIOLITH	Per Cent
Sodium fluoride	85
Dinitrophenol	10
Potassium bichromate	5

TANALITH—was Triolith, to which about an equal quantity of an arsenic salt, such as sodium arsenate, was added.

MINOLITH—was Triolith or Tanalith, to which was added two or three times its own weight (more or less) of a fire-retarding salt, such as ammonium phosphate, or other suitable material that does not react unfavorably with the preservative.

The original Triolith, Tanalith, and, to a lesser extent, Minolith were used in the United States and Central America in the 6 or 8 years preceding 1932. Since that time, the formulas have been changed by considerably increasing the percentage of chromium salts. In Germany, the new salts are known as Triolith-U and Thanalith-U; but in the United States, they are being sold and used under the original names of Triolith and Tanalith. In the patent covering the new formulas (U.S. 1,957,873, May 8, 1934), the claims are sufficiently broad to allow considerable variation in the proportions of the different ingredients, but typical examples are as follows:

TRIOLITH (Triolith-U)	Per Cent
Sodium fluoride	55
Potassium bichromate	35
Dinitrophenol	10
TANALITH (Thanalith-U)	
Sodium fluoride	25
Sodium chromate	37½
Di-sodium arsenate (anhydrous)	25
Dinitrophenol	12½

Detailed service records on installations of timber treated with the original Triolith or Tanalith are not yet available in satisfactory volume or age, but there is enough evidence to show that these preservatives are very effective when intelligently applied. Although the new formulas are being used in the treatment of large quantities of timber, they have come into commercial use too recently to have established usable service records. However, the evidence from laboratory tests and accelerated field tests indicates that they provide preservatives more resistant to leaching than the old Wolman salts.

Zinc-meta-arsenite (Z.M.A.).—Zinc-meta-arsenite is prepared by dissolving zinc oxide and arsenic trioxide (or equivalent compounds) in water that has been acidified with acetic acid. It is covered in United States patents 1,659,135 (1928) and 1,984,254 (1934). After the preservative is injected into wood, the acetic acid is said to evaporate, leaving behind the relatively insoluble meta-arsenite of zinc. This latter salt is said to be very resistant to leaching by ordinary soil moisture but is claimed to dissolve and produce a toxic solution in the presence of the acids secreted by fungi. That the insoluble salt is formed, or that the preservative in the timber is appreciably resistant to leaching, is disputed by some investigators. Shortly after its introduction about 1927, zinc-meta-arsenite was rather widely used in the United States in the treatment of poles, timbers, and, to a lesser extent, ties; more recently, the quantity of timber treated with this preservative has declined. The service records available to date are insufficient to show how this preservative compares in effectiveness with zinc chloride. It has given some good and some rather poor results.

PAINTS AND STAINS

Ordinary mineral-pigment paints, such as are used for house painting, are not to be classed as wood preservatives and would need no mention in this discussion were it not for the very general belief that they are effective in controlling decay. Aside from its decorative function, paint is used primarily to protect wood from the roughening, checking, and warping that ordinarily develop when unprotected material is exposed to the weather. Since the paint merely forms a film over the surface of the wood, it obviously cannot be expected to prevent decay. The linseed oil in the paint may penetrate into the wood to a very slight extent, but this ingredient is not toxic to wood-destroying fungi and cannot noticeably hinder their growth. The insoluble pigments of the ordinary paints are also nontoxic, or practically so.

Certain ingredients can be added to paint to make the film toxic to fungi. This is done in special cases to prevent the discoloration of the paint film by molds ("mildew"), which sometimes cause considerable trouble. However, even toxic paints are not to be considered as satisfactory preservatives. This is particularly true in view of the general practice of applying the coatings only to the exposed surfaces. The hidden parts are usually more subject to fungus attack than are the faces which can be reached with paint. Even when a board is completely painted on all surfaces before being built into a structure, the relative fragility and general inadequacy of the coating will make it ineffective in protecting the wood against decay for any marked period of time. Paint may actually encourage decay by retarding the evaporation of moisture that has gained entrance through an unpainted surface, a check in the wood, or a crack in the paint coat over a joint. This frequently happens at the bases of porch columns, the lower corners of window sash, and other similar locations.

Painted surfaces are resistant to attack by powder-post beetles and dry-wood termites and perhaps other insects. However, the wood is not completely protected unless it is painted on all surfaces to which the insects may gain access. Furthermore, such protection will last only so long as the integrity of the coating is maintained.

Stains that consist of pigment, linseed oil, and a volatile thinner have no value in preventing decay and probably are less effective than ordinary paints against insect attack. Stains of this character leave a less continuous film on the wood surface than do paints. On the other hand, stains that contain considerable percentages of ordinary coal-tar creosote may give some degree of protection against both insects and decay. When applied by the customary dipping or brushing methods, however, the protection cannot be very lasting, because of the small amount of creosote absorbed.

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CHAPTER V

PREPARATION OF MATERIAL FOR TREATMENT

A few minor wood-preserving processes give best results when applied to green timber, the Boucherie method even requiring that the bark be retained. But before adequate treatment can be obtained by any of the commercial methods in common use in this country, freshly cut wood must be properly prepared for processing. Such conditioning may involve one or more of the following steps: peeling, air seasoning, steaming and vacuum, boiling under vacuum, and possibly such mechanical preparation as adzing and boring, framing, and incising.

PEELING

As bark is virtually impermeable to liquids, its removal is a very essential step in the preparation of *round* timbers for treatment. This applies to all processes, except the few minor ones in which the preservative is injected through the ends of the timbers. Sawed and hewed products naturally do not require peeling, unless they have wany edges or round sides, as in the case of railway ties made from small trees by sawing or hewing two parallel faces. Bark is further detrimental in that it retards seasoning, harbors wood-boring insects, and encourages decay.

In the spring and early summer, when the cambium is soft and slippery, the bark can be peeled quite easily from most timbers with an ax or spud. But during the rest of the year it is so tenacious that a draw shave may be required for its complete removal. Steaming or boiling timber for two or three hours so softens the cambium that the bark may be easily peeled at any season, and this method is commonly employed with veneer logs. It has not yet been found practicable for the commercial preparation of wood for preservative treatment, however.

Peeling is almost invariably done by hand, since economical mechanical devices have not yet been perfected for barking heavy material. Furthermore, it is desirable to remove the bark in the woods soon after the timber is cut, for this reduces the weight and facilitates the handling of the timbers, permits seasoning to begin promptly, and eliminates the waste-disposal problem. Mechanical peeling could be employed only at a concentration point or seasoning yard where power is available.

In peeling softwoods, even the thin inner bark must be removed as completely as practicable, since it generally falls off after treatment, exposing untreated wood to possible attack by decay and other agencies of deterioration. However, small strips of inner bark may be permitted to remain on timber that is to be impregnated by the more thorough pressure processes, since the longitudinal and tangential movement of preservative from beneath the peeled areas will enable the chemical to reach the wood under the strips. The need for clean peeling is recognized by the American Wood-Preservers' Association (2) in its specification 2*c*, "Standards for the Purchase and Preservation of Treatable Timber," which states:

> **Peeling.**—All round timbers shall be thoroughly peeled before treatment. No piece shall be considered thoroughly peeled unless all of the rough bark and at least 80 per cent of the inner bark shall have been removed. In no case shall any piece of inner bark be over ¾ inch wide or over 8 inches long, and there shall be 1 inch of clean wood surface between any two such strips.
>
> Should the strips of inner bark remaining on the pole be less than ¾ inch wide, the clear space required between any two such strips may be proportionately less than 1 inch.
>
> No circumference may have more than 20 per cent of its surface covered with inner bark, although the entire surface of the pole may contain less than the allowable 20 per cent.

The specifications of this same association, covering the butt treatment of cedar and chestnut poles by the open-tank processes (dipping and hot-and-cold bath), are even more exacting and specify that *all* the inner bark shall be removed from the 3-ft. ground-line area* by shaving. Complete elimination of the bark over this area is essential, since artificial pressure is not used to facilitate impregnation and also because the sapwood of the species involved may be relatively resistant to penetration.

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* The ground-line area of a pole is the surface area extending from 1 ft. above to 2 ft. below the point that will be at the ground level when the pole is placed in service.

Care must be exercised, of course, to avoid removing too much wood, as this reduces the thickness of the treatable sapwood, which in cedar and chestnut is normally only ½ to ¾ in. in depth. Deep shaving may also so reduce the diameter of a pole as to necessitate placing it in a lower size class. Very thorough peeling, at least over the ground-line area, is also important for fence posts that are to be treated by nonpressure processes.

POLE SHAVING

Pole-shaving machines are in use at a number of plants that treat pine poles. The outer bark is ordinarily removed by hand from the timbers in the woods, the machines being used, after the poles arrive at the plants, to insure the complete elimination of the tenacious inner bark as well as to smooth off knots and other irregularities on the pole surface. The result is a product that is smoother, straighter, and definitely more attractive to the consumer than any that can be prepared by hand. The cost of machine shaving is said to be no greater than that of hand trimming.

The machines used at the different plants have not been standardized and differ from each other in various details. In most of them, the pole itself is revolved and moves forward slowly, contacting rapidly rotating knives which are set in cutter heads at the ends of long arms which follow the general contour of the timber (Fig. 28). In at least one type of machine, however, the cutter heads revolve around the pole. The depth of cut can be regulated as required, the objective generally being to clean the pole thoroughly while removing as little wood as possible. The operating speed varies with different machines and sizes of timber; poles of average size can be shaved in some machines at the rate of about 1000 lin. ft. per hour. Since its introduction into this country about 1932, the practice of machine-shaving pine poles has definitely grown in favor.

AIR SEASONING

In applying certain minor impregnation processes using water solutions, it is important to treat the wood while it is still green (unseasoned). Such is the case with the various forms of the Boucherie and standing-tree methods, in which water leaves the wood as preservative enters; and with the Osmose and other diffusion methods, in which the chemicals diffuse from the treating solution into the water in the wood. With all other treating methods, however, the presence of any considerable amount of free water in the cell cavities will retard or even prevent the entrance of the preservative liquid. Thus, the application of a superficial oil treatment, such as brushing or the hot and cold bath, to green or wet wood is ineffectual; even with the pressure processes it is impossible to impregnate freshly cut wood satisfactorily, unless such artificial conditioning treatments as steaming and vacuum or boiling under vacuum are resorted to prior to the actual injection of the preservative.

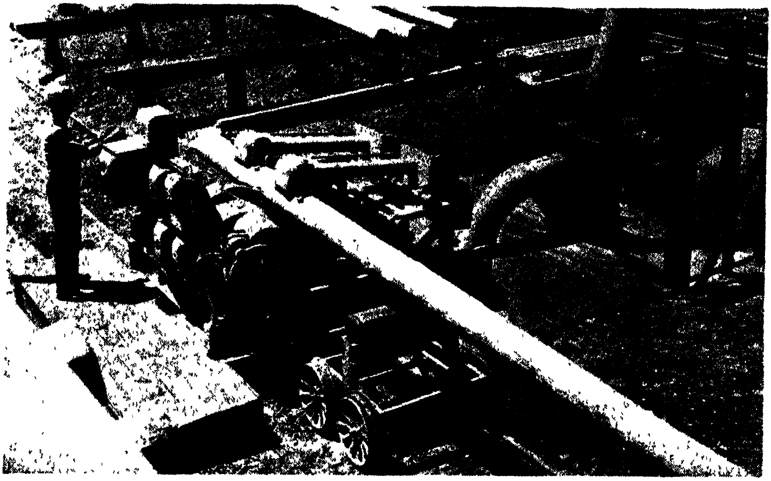

FIG. 28.—Shaving a southern pine pole by machine. (*Taylor-Colquitt Co.*)

The most common method of preparing green lumber and timber for treatment is to pile it out of doors and allow it to air season. Unseasoned wood that is exposed to the open air, but protected from rain, will gradually dry out until it comes into approximate equilibrium with the average relative humidity of the air. In very dry parts of the country the equilibrium moisture content of small material may be as low as 5 per cent, while in regions of high humidity and in the wet seasons of the year it may be in excess of 20 per cent; throughout most of the United States the average amount of moisture in thoroughly seasoned stock falls within the general limits of 12 to 15 per cent of the dry weight of the wood. However, the atmospheric humidity varies during the year, and even from day to day, and the moisture content of thoroughly air-dry wood tends to fluctuate accordingly; the rate of change depends largely upon the size of the timber involved. In thin boards, the moisture content can fluctuate rapidly; while in poles, piles, and other heavy timbers, the change is very slow, at least below the surface layers. For this reason, heavy material does not get so uniformly dry as thin stock and may require years rather than months to become thoroughly air seasoned.

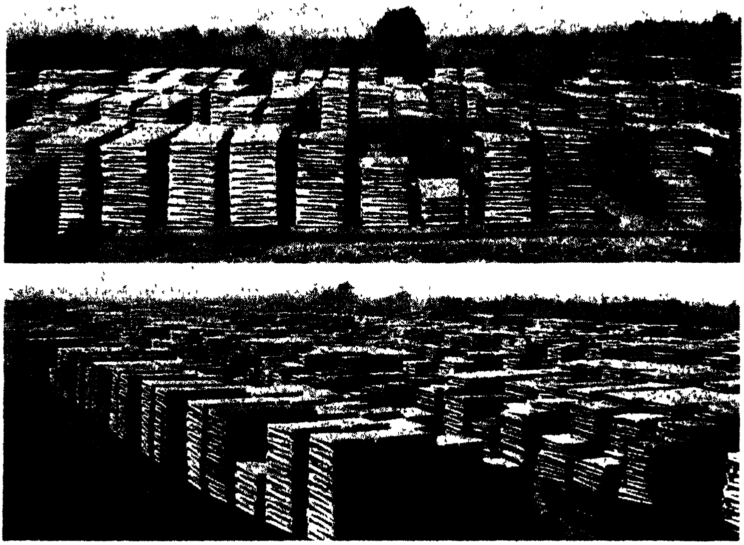

Fig. 29.—General views of a crosstie seasoning yard. (*American Creosoting Co.*)

The seasoning yard (Fig. 29) should be located on well-drained ground which is open to the wind. Low, damp sites are poorly suited for drying and also encourage decay. Unless there is good air drainage, damp air may settle in the yard, especially at night, and definitely retard seasoning. The yard should be kept clean and sanitary at all times. No weeds, waste wood, or other debris should be allowed to accumulate, and storm water should be drained away promptly. The seasoning piles should be raised from 1½ to 2 ft. above the ground on permanent foundations of well-treated wood or other nondecaying material and should be well ventilated beneath (Figs. 32, 33, 35, and 37). They should also be spaced far enough apart to be accessible for inspection or other purposes. The piles should be arranged along streets, or main alleys, which preferably run in the direction of the prevailing winds. These streets should be of sufficient width to accommodate the necessary tracks, cars, trams, and timber-handling machinery required for moving the timber to and from the piles (Fig. 32 and frontispiece). In those yards in which the streets are two pile widths apart, narrower rear alleys should be left between the piles to provide ventilation and accommodate drainage ditches.

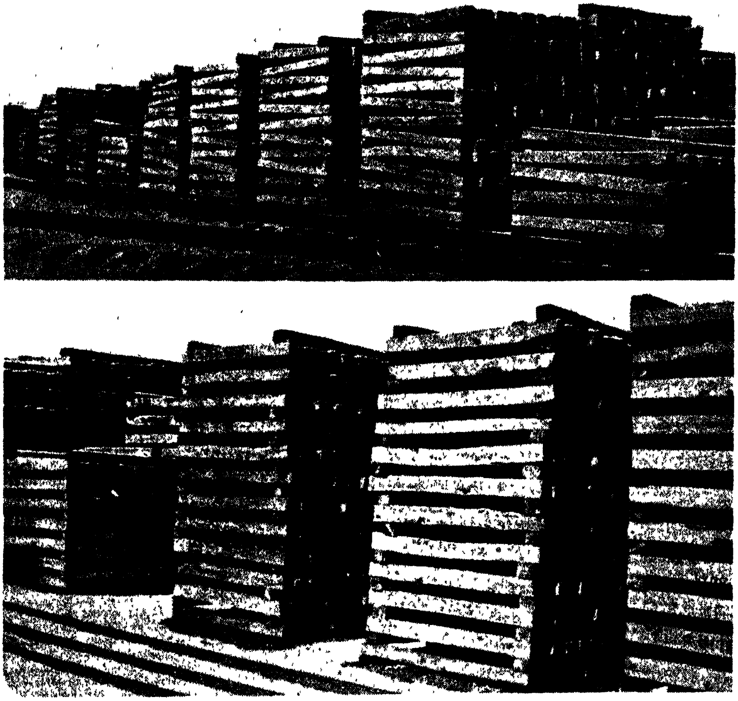

FIG. 30.—Crossties piled for air seasoning by 1-by-9 method (upper) and 2-by-9 method (lower).

Figure 30 shows some of the more common methods of piling crossties. The 1-by-9 pile is the most common, but the 2-by-9 type is also used in many yards. Products of this type are "self-stuck;" *i.e.*, the ties themselves are used as stickers, or crossing strips, to separate the successive layers and insure adequate ventilation within the piles. Switch ties may be placed in 1-by-9 piles, but the methods of stacking shown in Figs. 31 and 32 are much more generally used. An approved method of piling lumber is also shown in Fig. 31.*

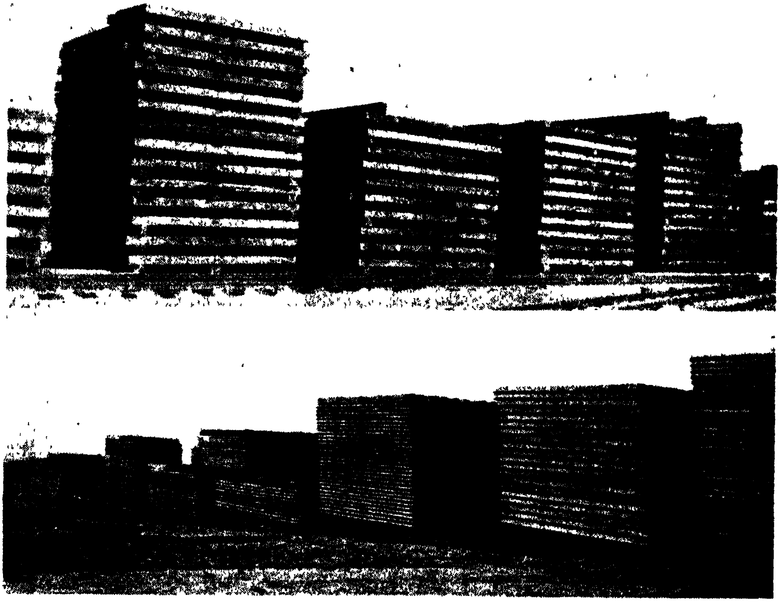

FIG. 31.—Switch ties (upper) and lumber (lower) piled for air seasoning.

A good piling method for poles, piles, and other heavy timbers is shown in Fig. 33. Special crossing strips are usually employed for such material and these should be very substantial, so as to withstand the heavy loads imposed upon them and to provide plenty of air space between the successive layers of the pile. Pine poles are especially susceptible to damage during seasoning, and every precaution should be taken to avoid deterioration. The use of temporary roofs (Fig. 34) is particularly favorable to safe seasoning. In the past, it has been common practice to stack cedar poles in solid piles (Figs. 35 and 90), but the open style of pile (Fig. 36) permits better seasoning with less opportunity for decay. It is important that the consumer maintain sanitary conditions for cedar poles awaiting use, since only the butts of such timbers are creosoted (Fig. 37).

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* For a more detailed discussion of piling practice and other factors affecting the air seasoning of wood, the reader is referred to Mathewson (18), as well as the following publications:

Anonymous: Seasoning, handling, and care of lumber (manufacturers' ed.), U. S. Department of Commerce, National Committee on Wood Utilization (1929).

Henderson, Hiram L.: The air seasoning and kiln drying of wood, Chaps. III, IV, J. B. Lyon Co. (1936).

Koehler, Arthur: The properties and uses of wood, Chap. VII, McGraw-Hill Book Company, Inc. (1924).

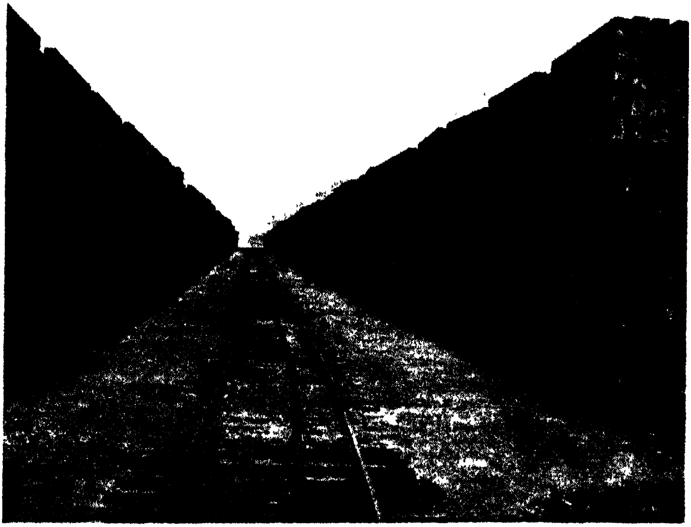

FIG. 32.—Street in seasoning yard, showing oak switch ties piled on special "crossers." Note double-gauge track.

The length of time required to air season timber sufficiently for treatment is dependent upon the various external factors that determine the rate of drying (18) as well as upon the size and character of the products involved. Large timbers season very

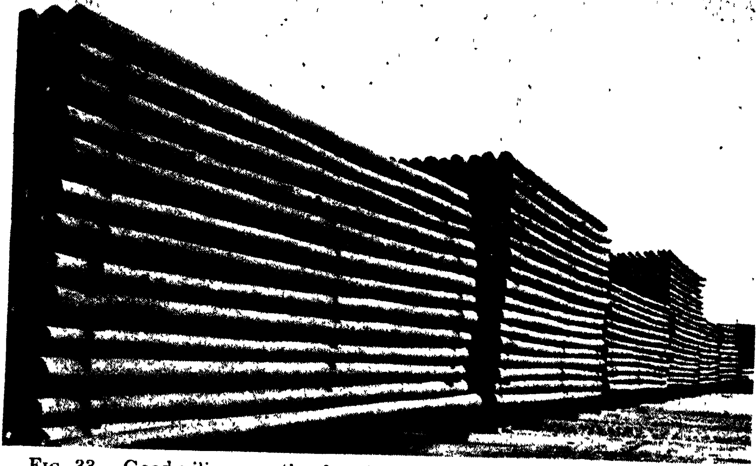

FIG. 33—Good piling practice for air seasoning poles and piles. Note clean condition of yard, foundations of creosoted wood, ground clearance, and use of creosoted crosspieces for separating courses of timbers. (*International Creosoting and Construction Co.*)

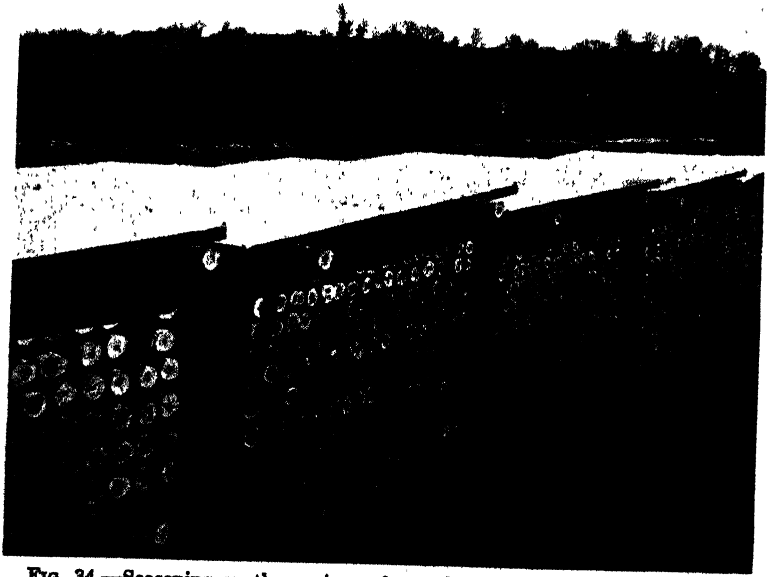

FIG. 34.—Seasoning southern pine poles under temporary roofs. The roofs keep out storm water and thus promote seasoning and reduce danger of decay. (*Cincinnati Gas and Electric Co.*)

slowly and, even after a year or more of drying, may still have a relatively high moisture content in the interior, although the outside may be thoroughly dry. It is not necessary that such timbers be seasoned throughout before treatment, but enough water must be removed from the area to be penetrated to make room for the preservative. The most favorable moisture content for treatment has not been determined, but it probably varies somewhat for different species, preservatives, and methods of treatment. Throughout the higher range of moisture contents, the ease of impregnation unquestionably increases as the amount of water in the wood decreases, but there is some evidence to indicate that, after a certain optimum point is passed, further seasoning may be a hindrance rather than a help. Thus, the surface

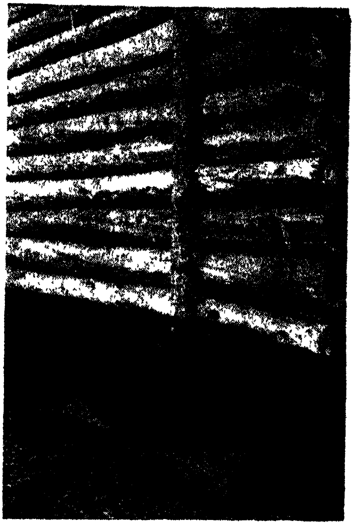

Fig. 35.—Cedar poles in solid seasoning pile.' Note clean ground, good clearance, and creosoted foundation timbers. (*Western Red and Northern White Cedar Association.*)

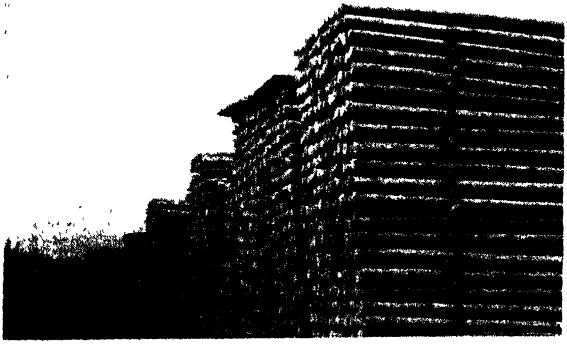

Fig. 36.—Cedar poles in open seasoning piles. (*Courtesy of J. P. Wentling.*)

layers of certain timbers that have been seasoned too long may become definitely more resistant to treatment than is normally the case; this condition has been referred to as *casehardening*, although, as MacLean (14) points out, the term *surface hardening* is to be preferred. There is undoubtedly a wide range of moisture content, however, within which good treatment is possible.

Since no definite rules can be laid down to determine the most advantageous seasoning time, each operator must decide upon the best practice for his particular location, climatic conditions, and kind of timber. For this reason, the seasoning practice followed at different treating plants varies widely. Some indication of the wide range of seasoning periods actually used throughout the country, even in drying a given species, will be found in Table VI. It is believed that a thorough study of the subject would show the desirability of much greater uniformity in air-drying practice as well as disclose the optimum range of moisture content for the treatment of various species, forms, and sizes of timber. It should then be possible, by mechanical means, to determine when a stack of material has reached the proper degree of seasoning for treatment.

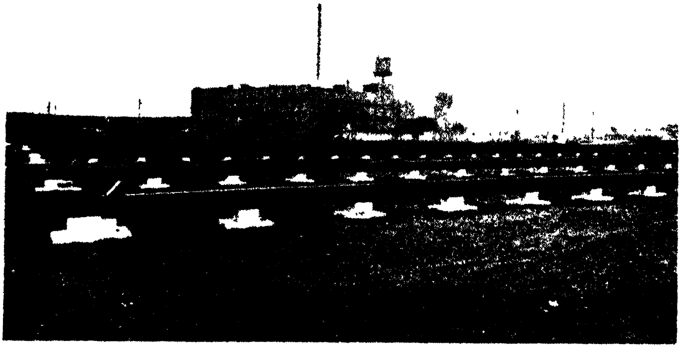

FIG. 37.—Sanitary storage yard and pile foundations for storage of butt-creosoted cedar poles. (*Commonwealth Edison Co.*)

Untreated material that is piled for drying or storage is exposed to two serious forms of deterioration—decay and checking—both of which are dependent upon the weather. Checking is most severe under conditions that promote rapid drying but may be minimized by using proper piling methods and by applying

TABLE VI.—AIR-SEASONING PERIODS USED BY WOOD-PRESERVING PLANTS IN THE UNITED STATES, 1930–1931 (14)

Species	Form of timber	Region in which plants are located*	Seasoning period, months
Beech	Ties	Interior eastern	6
	Ties	Interior eastern	8 to 12
	Ties	Atlantic	6 to 8
Cottonwood	Ties	Interior western	12
Douglas fir, mountain	Ties	Interior western	9 to 12
	Ties	Interior western	6
	Ties	Interior western	1 to 1½
	Ties	Interior western	3†
Douglas fir, coast	Ties	Interior western	10 to 12
	Ties	Interior western	6 to 7
	Ties	Interior western	3
	Ties	Pacific	10 to 12
	Ties	Pacific	6 to 12
	Ties	Pacific	3 to 12
	Piling	Pacific	12
Eastern hemlock	Ties	Interior eastern	8 to 12
Engelmann spruce	Ties	Interior western	6 to 8
	Ties	Interior western	8 to 10
	Ties	Interior western	3†
Gum	Ties	Southern	3 to 4
	Ties	Southern	4 to 6
	Ties	Southern	10 to 12
	Ties	Interior eastern	8 to 12
Lodgepole pine	Ties	Interior western	8 to 12
	Ties	Interior western	3 to 6
Maple	Ties	Interior eastern	6
	Ties	Interior eastern	8 to 12
	Ties	Atlantic	6 to 8
Ponderosa pine	Ties	Interior western	3 to 6
	Ties	Interior western	8 to 12
Red oak	Ties	Interior eastern	12
	Ties	Interior eastern	10 to 14
	Ties	Interior eastern	8 to 12
	Ties	Interior eastern	12 to 14
	Ties	Interior eastern	14 to 18
	Ties	Interior western	6
	Ties	Southern	10 to 12
	Ties	Interior eastern	10 to 12
	Ties	Interior eastern	8 to 12
	Ties	Southern	10 to 13
	Ties	Southern	12 to 13
	Ties	Southern	12 to 14
	Ties	Southern	15 to 16

TABLE VI.—AIR-SEASONING PERIODS USED BY WOOD-PRESERVING PLANTS IN THE UNITED STATES, 1930–1931 (14)—(*Continued*)

Species	Form of timber	Region in which plants are located*	Seasoning period, months
Southern yellow pine	Ties	Southern	2
	Ties	Southern	2 to 3
	Ties	Southern	3 to 4
	Ties	Southern	3 to 5
	Ties	Southern	5 to 6
	Ties	Interior eastern	5 to 6
	Poles and piling	Southern	2 to 3
	Poles and piling	Southern	3 to 4
	Ties	Atlantic	5 to 6
Western hemlock	Ties	Interior western	12
	Ties	Interior western	6
Western larch	Ties	Interior western	9 to 12
White oak	Ties	Interior eastern	14 to 18
	Ties	Atlantic	12 to 14
	Ties	Atlantic	10 to 12
Yellow birch	Ties	Interior eastern	6
	Ties	Interior eastern	8 to 12
	Ties	Atlantic	6 to 8

* The Atlantic region comprises Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Delaware, West Virginia, and Virginia. The southern region comprises Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Florida, Arkansas, Louisiana, Oklahoma, and Texas. The interior eastern region comprises Michigan, Ohio, Indiana, Illinois, Wisconsin, Minnesota, Iowa, Missouri, and the eastern parts of North Dakota, South Dakota, Nebraska, and Kansas. The interior western region comprises Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and the western parts of North Dakota, South Dakota, Nebraska, and Kansas. The Pacific region comprises Washington, Oregon, and California.

† Partly seasoned in woods before delivery to plant.

suitable coatings or antichecking irons to the ends of the timbers. In wood products of the size and type usually subjected to preservative treatment, surface checking is seldom so severe or so extensive as end checking, although it may sometimes seriously impair the general utility of the timbers. When surface checking does prove to be a source of trouble, it may be controlled to some extent by decreasing the space between the timbers and, in this way, reducing the circulation within the pile. Thus, with poles, piling, and lumber, the thickness of the crosspieces and the distance between the edges of the individual sticks may be varied to change the rate of seasoning. With ties, some measure of control of the drying rate can be obtained by varying the distance between the piles themselves as well as by altering the spacing between the timbers in the individual courses of the pile. Each locality and form of material provide a separate problem, and the plant operator must determine for himself the precise method of piling that gives adequate seasoning with a minimum of surface checking under his own yard conditions.

End checking may be quite severe in heavy material. Hardwood stock is especially susceptible to such deterioration; but in "boxed-heart" timbers (containing the pith), even softwoods may be seriously affected. This form of checking is not greatly influenced by the method of piling, and must be controlled in other ways. Antichecking irons, several styles of which are shown in Fig. 38, are commonly used on hardwood crossties and switch ties. In the past, the general practice was to insert these devices in the ends of the ties only when the checks actually began to develop, thus making it possible to place the irons to best advantage; more than one iron was applied to an end, if needed. Difficulties naturally arose because the necessary periodic inspection of the nonironed ties was often delayed until the checks had opened too far to be properly controlled. As a result, this procedure has long been considered to be generally unsatisfactory by many railways. The American Railway Engineering Association now recommends (6) that all hardwood ties should have antichecking irons applied prior to, or at, the time they are delivered to the yard and stacked for seasoning; the irons should be so placed as to cross at right angles the greatest possible number of rays on the ends of a tie. Even this practice is not entirely satisfactory, however, since it is not possible to anticipate accurately the location and shape of the potential checks.

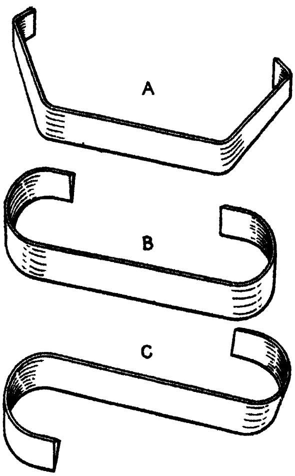

FIG. 38.—Antichecking irons. (*A*) Beegle iron, (*B*) C-iron, (*C*) S-iron.

Hardwood ties may check seriously at the ends despite the antichecking irons and without them may sometimes split wide open. It is the practice of one railway (7) to salvage split ties by closing the openings with a pneumatic clamp and inserting antichecking irons across the lines of separation. It is reported that two men can salvage about 30 ties per hour by this method. The ability of the irons to keep a check closed permanently, after it has once opened wide, is questionable, however. A more expensive, but probably more reliable, method for preventing a split from reopening, once it has been closed, is to bore a hole through the end of the tie, across the plane of cleavage, and insert a strong bolt. A device that is being promoted by one manufacturer, as a substitute for the bolt and nut, consists of a square iron bar that has been twisted. It has no nut or head but, when driven to a tight fit in the bolt hole, tends to hold the split parts firmly together (Fig. 39). Still another method of salvaging a split tie is to close the opening firmly within the jaws of a hydraulic jack and then bind the end of the tie with a substantial iron strap, using a tool that stretches the band very tightly around the tie and clamps the ends of the strap securely (Fig. 40).

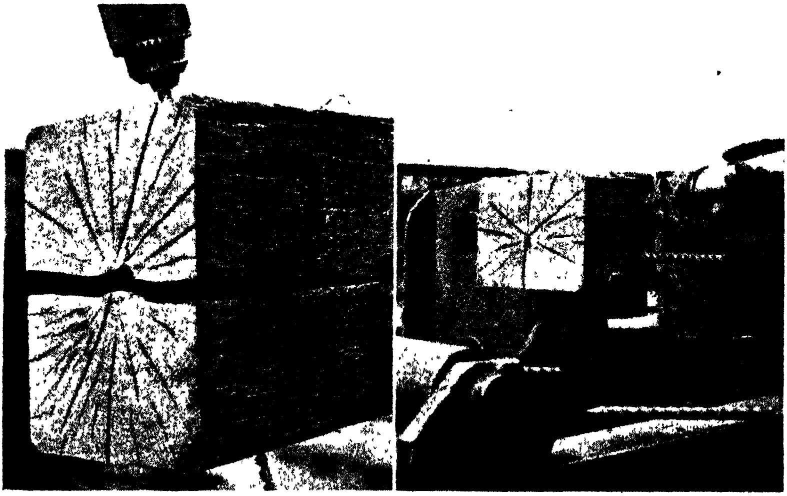

Fig. 39.—Metal-dowel method of closing badly split ties. (Left) drilling holes through end of split tie; (right) driving in spiral metal dowels while split is held closed between pneumatic jaws. (*C. B. and Q. R.R.*)

Experiments conducted at the U. S. Forest Products Laboratory have indicated the possibility of seasoning heavy material, without checking at either sides or ends, by treating it while green with a concentrated solution of common salt or certain other chemicals and then drying it in a kiln or in the open air (11). The extent to which this process has commercial application is not yet known.

End checking may also be reduced by coating the ends of lumber or timbers with materials that definitely decrease the rate of moisture loss through those surfaces. Ordinary mineral-pigment paints, when generously applied, are helpful in this respect. Thick coatings of paraffin are also effective but are not durable in hot weather. Even applications of fuel oil are said to be of some value, although they cannot be expected to yield such satisfactory results as coatings of substantial thickness, *e.g.*, the filled, hardened, gloss oil recommended by the U. S. Forest Products Laboratory (18) for end-coating lumber. Any coating used on material that will be treated after seasoning must be of such character as not to prevent satisfactory end penetration of the preservative.

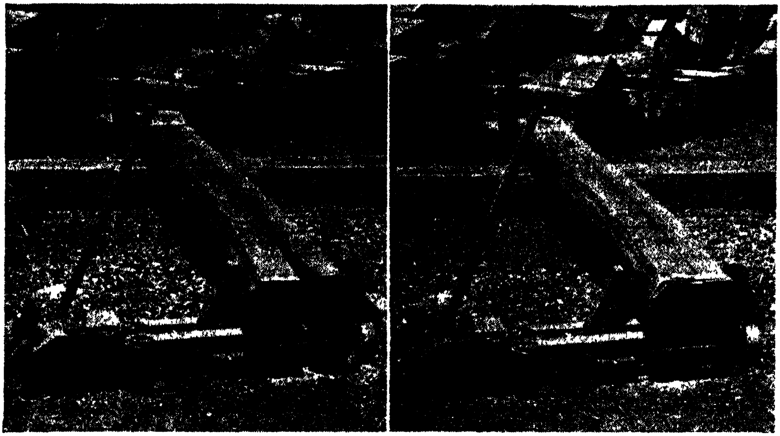

FIG. 40.—Greenlee hydraulic-jack method of closing and binding split ties. (Left) before closing split; (right) split closed and held by an iron strap. (*Greenlee Bros. and Co.*)

Sapwood material and the heartwood of nondurable species may become infected with decay (*storage rot*) in the seasoning pile, especially during warm, humid weather. Where this danger exists, the plant operator must be very careful to follow the best drying practice and also be constantly on the alert to detect the first sign of damage. The hazard is greatest in the South-eastern and Gulf states, and with ties and other timbers containing large percentages of sapwood; sap southern pine and sap gum ties and southern pine poles and piles are particularly susceptible to infection. Piling methods that encourage most rapid seasoning are least favorable to the development of decay. On the other hand, the rate of drying should not be so drastic as to cause serious checking of the timber.

Blue stain develops in green timber more quickly than does decay, and a few days of warm, humid weather may lead to almost complete staining of the sapwood. Heartwood, of course, is not infected. The fungi concerned do not damage the timber appreciably or have any marked effect on the subsequent penetration of preservatives, but the resultant discoloration does give the wood an unattractive appearance. Blue stain, however, is a warning of conditions that favor the rapid development of wood-destroying fungi, and seriously stained material should be examined carefully for decay.

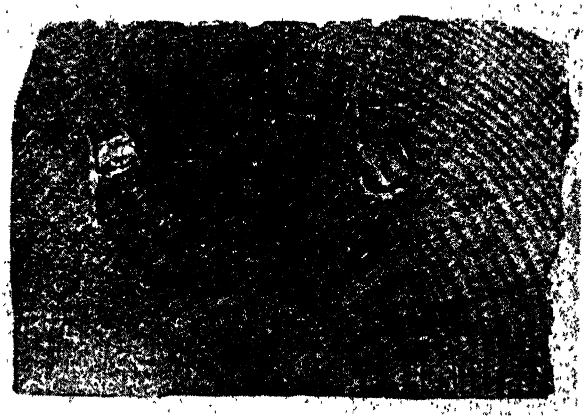

Fig. 41.—Southern pine tie culled because of decay exposed by trim saw of adzing and boring machine. (*A. T. & S. F. Ry.*)

The presence of decay is not always easy to detect in air-seasoned material, because the infection may be concealed within the wood. This is especially true with timber that is somewhat weathered or otherwise dirty and discolored. Consequently, in order to assist in inspection, end-trimming saws are often used on adzing and boring machines, especially in handling southern pine ties. The presence of decay will be more apparent on the fresh end surfaces thus exposed (Fig. 41), thereby facilitating the culling of infected ties. Similarly, in the final preparation of air-seasoned pine poles or piles for treatment, it is good practice to trim off the ends to permit better inspection for decay (Fig. 42).

Some plant operators, handling southern pine poles and piles, follow the practice of air seasoning the timber for a few weeks, or steam conditioning it, and then injecting about 4 lb. of creosote per cubic foot of wood by the Rueping process, after which the material is returned to the yard for further seasoning and to await purchase orders. The danger of fungus infection during the subsequent seasoning period is thus very much reduced, and the material may be held in the yard for long periods without much risk. When it is desired to complete the treatment, additional oil is injected into the timber to make up the total poundage specified. The extra handling involved in this method is expensive, but the added cost is usually compensated for by a reduction in the quantity of material that has to be culled for decay and by the improved penetrations obtained.

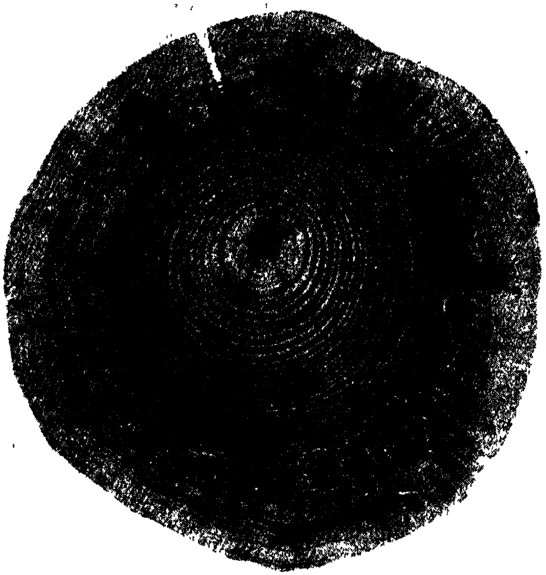

FIG. 42.—Sawing the end from this southern pine pile revealed extensive decay in the sapwood. (*U.S. Forest Products Laboratory.*)

Various attempts have been made to develop an inexpensive dip treatment, which can be applied to green poles and piles before they are stacked for air drying. A number of preservative oils and water-soluble salts have been tried out to determine their suitability for preventing both blue stain and decay during the seasoning period. One plant has even gone so far as to run the green material into a treating cylinder and give it a brief pressure impregnation with a preservative in water solution. Some such pretreatment may ultimately be found practical, but no standard practice has yet been worked out. The very cheap, superficial treatments have not proved sufficiently effective, while the more thorough methods are either too inconvenient or too expensive.

Unless all decay-producing fungi that have previously invaded the wood are killed by treatment, they may seriously impair the life of timber in service. The fungus will be destroyed if the infected area is thoroughly penetrated by the preservative, but any hyphae not reached by the toxicant may continue to grow and eventually destroy the untreated parts of the wood. One hundred per cent penetration of a timber naturally insures complete protection against this danger. Sterilization of infected wood may also be accomplished by steaming or otherwise heating the timber until all parts of it have been subjected to a temperature of not less than 150°F. for a period of 1 hr. or more (5, 9). This can be done readily with material of moderate size, but it is not so practical for very large poles, piles, and construction timbers, because of the long heating periods required. For example, a green pile with a butt diameter of 18 in. would have to be steamed for about 15 to 16 hr. at 20 lb. pressure (14) before it would attain a temperature of 150°F. at the center.* A seasoned pile of this same size would require even more time.

ADZING AND BORING

Railway ties, especially those with hewed surfaces, are now commonly adzed and bored (Fig. 43) just before treatment, although in some cases they may be subjected to one operation but not the other. The purpose of the adzing is to provide smooth, even bearing surfaces for the rail bases or for the tie plates upon which the rails will rest. Where this is done, the rails or plates will not have to find their bearing by crushing down or wearing away the inequalities in the upper surface of the tie. The need for carrying out this operation before the timbers are treated is apparent, as otherwise the removal of wood will reduce the thickness of the impregnated zone and may even expose the untreated interior of poorly-penetrated ties. Preboring has several very definite advantages. It permits the spikes to be inserted into ties with less crushing and tearing of the wood and also gives them greater resistance to withdrawal (3, 12) than when they are driven into unbored timbers. Furthermore, the preservative enters the holes and penetrates the wood surrounding them, thus obtaining especially good absorption and penetration in the vulnerable rail-base area. When spikes that were driven without preboring begin to loosen, water collects in the holes, and fungi are able to gain entrance into the untreated interior of the timber. This decay, in turn, accelerates the further loosening of the spikes (*spike killing*) and results in a weakening of the rail-base area of the tie.

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* The actual steaming period could be shortened somewhat, owing to the fact that heat continues to flow toward the center of a timber after the steaming has been discontinued.

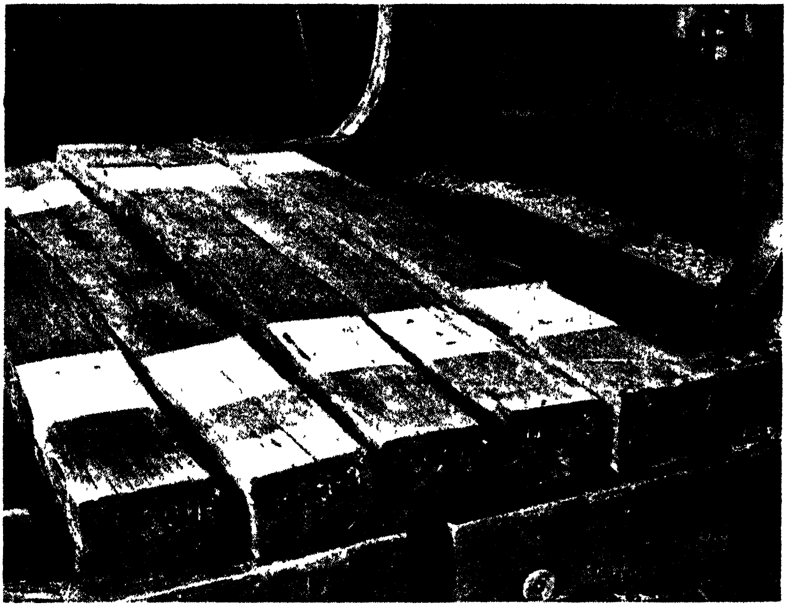

FIG. 43.—Crossties showing rail-base area after adzing and boring. Note S-irons and identifying characters.

The first adzing and boring machines operated in the United States were installed in 1911 by the Northern Pacific and the Santa Fe railways, but such equipment is said to have been used in Europe more than 20 years before that time (12). The present-day machines may also be equipped to trim the ends of the ties and stamp identification marks on them. The ties are brought from the seasoning yard in tram cars and loaded upon a conveyor which carries them through the machine. They are automatically centered and placed in proper position for each operation in turn. After passing through the machine, the ties are reloaded upon the tram cars and moved on to the cylinder for treatment.

When trimming is done, it is the first operation in the machine and is accomplished by a pair of circular saws, which cut a slice from each end of the tie as the conveyor carries it past them. This step is most commonly used with pine ties, being designed to facilitate inspection for interior decay. The operation also squares up the ends and evens the lengths of the ties, but this is not of great importance. Ties containing antichecking irons cannot be trimmed, unless the irons are first removed or a very deep cut is taken.

After leaving the trim saws, a tie passes over two sets of knives mounted in cutter heads, and these adze the rail-base areas to the desired contour. The bearing surface may be left flat or be grooved, according to the contour of the bottom of the tie plates that are to be used, and it may be canted or level. Following the adzing operation, the tie stops for a brief interval over two gangs of bits, which rise from beneath the timber and bore holes in the adzed areas for the spikes that will be used to hold the rail and tie plates. The number, size, and position of the holes vary somewhat with different weights of rail, kinds and sizes of tie plates, sizes of spikes, and kinds of wood as well as with different railways, and the machine must be adjustable in this respect. The American Railway Engineering Association recommends (1) that the diameter of the holes in hardwood ties be made $\frac{1}{16}$ in. less, and in softwood ties $\frac{1}{8}$ in. less, than the size of the cut spikes to be used; thus, for $\frac{9}{16}$-in. cut spikes, the holes should have a diameter of $\frac{1}{2}$ in. in hardwoods and $\frac{7}{16}$ in. in softwoods. Four rail-spike holes are usually bored at each rail bearing, although it is customary to use only two spikes at a time. When plates are to be fastened to the ties independently of the rail fastenings, extra holes of suitable size must be bored to receive the necessary spikes or lag screws. The openings are bored entirely through the timbers, except in ties that are to be used in direct-current electric lines having covered track. It is stated (1) that, in such installations, electrolysis causes serious corrosion to spikes inserted in holes extending completely through the ties. In other types of track, the through openings have the advantage of permitting the prompt drainage of any water that may enter around the spikes or collect in the empty holes.

Branding or marking the ends of the ties (Figs. 41 and 43) is the last operation in the machine. It is accomplished by hammers driven against the wood by pneumatic pressure. Either end or both may be branded. The hammers can carry up to five characters each, and, since the figures are interchangeable, many combinations of symbols can be obtained. Thus, it is possible to indicate the ownership of the ties; the species, treatment, date, size of rail and type of plate for which they are prepared; and other desired information. Ties containing antichecking irons can be branded, if the branding characters are made of suitably hard steel.

Adzing and boring machines may be set up in different ways, according to the needs of the individual plant. In many installations, the ties are fed into one end of the machine and come out at the opposite end. In this case, the empty trams, after bringing their loads from the yard to the conveyor of the machine, are pushed around a circular track to the outfeed side of the machine, where they are reloaded with ties that are ready for treatment. Another arrangement is to have the ties pass through the machine and then, by means of a mechanical conveyor, return to the infeed side. With this layout, the unloaded trams are merely shoved along the track a few feet to the outfeed end of the machine and reloaded with the adzed and bored ties.*

INCISING

Incising consists in making slitlike holes in the surfaces of material to be treated, so that deeper and more uniform penetration of preservative may be obtained. The incisions made in sawed material are commonly ¼ to ¾ in. long and about ⅛ in. wide, with the long direction approximately parallel with the grain of the wood. They may be from ⅜ to ¾ in. deep. This step in the preparation of timber is used extensively on sawed Douglas fir products and cedar pole butts and is also employed to some extent on crossties of such species as lodgepole pine, beech, birch, and maple. It is of value only in woods that are resistant to side penetration but treat fairly well along the grain. In the region in which it is produced, it is common practice to incise all sawed Douglas fir 3 in. or more in thickness before treatment.

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* Various adzing- and boring-machine layouts are discussed in *Am. Wood-Preservers' Assoc., Proc. 17th Ann. Meeting*, 465–478 (1921); *Proc. 18th Ann. Meeting*, 315–323 (1922).

The improvement in uniformity of penetration, obtained as a result of incising (Fig. 66), is attributable to the fact that preservatives move along the grain (endwise) of the wood much more readily than across the grain (sidewise). The incisions expose end-grain surfaces at frequent and regular intervals and are so spaced that the preservative, in spreading out from them, can penetrate the entire exterior shell of wood to the depth of the openings. In order to conserve the strength of the timber, no unnecessary holes should be made, but there must be a sufficient number to insure complete and uniform distribution of preservative with reasonable intensity of treatment. The spacing necessary to obtain satisfactory results varies to some extent with the species involved.

Since there is very little movement of preservative below the bottoms of the holes, incising does not materially increase the maximum depth of penetration that will be obtained. Its chief advantage lies in the fact that it makes possible a uniform penetration of not less than the depth of the holes. Incising is especially important in the resistant heartwood faces of ties and timbers and in the sapwood of cedar poles to be treated by the hot-and-cold-bath process. In the former classes of material, the holes usually have a depth of ½, ⅝, or ¾ in.; while in the poles, they are either ⅜ or ½ in. deep. The incisions in cedar poles are made only over the 3-ft. ground-line area (Fig. 44) and have a definite secondary advantage in that they cause concentration of the preservative where the greatest decay protection is needed. Poles are incised just prior to treatment, but railway ties and sawed timbers may be so prepared either before or after seasoning. Harkom (8) found that incising beech, birch, and maple ties before air seasoning had no appreciable effect on the rate of drying of the wood but did cause a slight reduction in the amount of checking that occurred. This may be of some significance in the handling of these particular species, since such ties often check so severely in seasoning as to be rendered worthless.

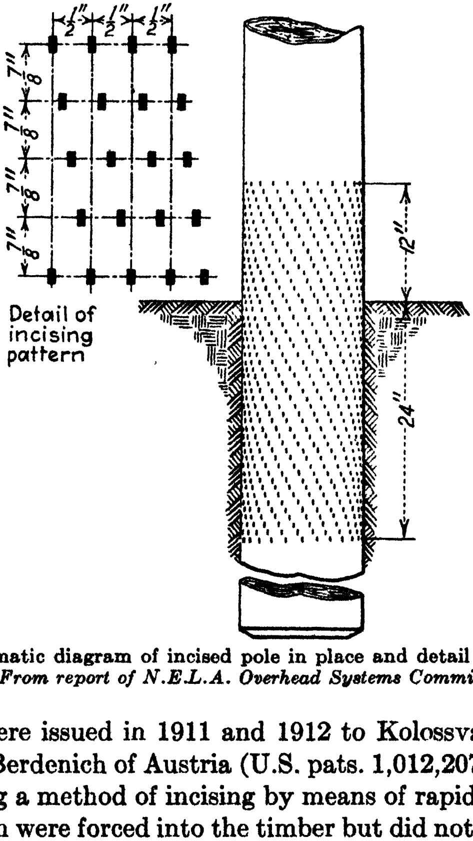

FIG. 44.—Schematic diagram of incised pole in place and detail of one incising pattern. (*From report of N.E.L.A. Overhead Systems Committee*, 1921.)

Patents were issued in 1911 and 1912 to Kolossvary, Haltenberger, and Berdenich of Austria (U.S. pats. 1,012,207 and 1,018,624) covering a method of incising by means of rapidly revolving needles which were forced into the timber but did not remove any wood substance. Apparently, the first practical commercial incising machine was built in 1915 by the Columbia Creosoting Co., of Portland, Ore. (4). On Jan. 8, 1918, U.S. patent 1,252,428, covering the spacing of incisions for Douglas fir, was issued to O. P. M. Goss, of the Association of Pacific Coast Creosoting Companies; and on Oct. 6, 1919, the right to use this patent was dedicated to the public by the foregoing association. In 1920, an incising machine was built for the St. Helens Creosoting Co., of St. Helens, Ore., by Greenlee Bros. and Co.; and since that time many such machines have been installed.

The present-day machines for incising ties and sawed materials (Fig. 45) consist essentially of four revolving drums fitted with teeth so spaced as to give the desired pattern (U.S. pat. 1,646,955, issued Oct. 25, 1927, to D. W. Edwards and J. H. Mansfield of Greenlee Bros. and Co.). Two of the drums revolve around vertical axes and engage the sides of the timbers, while the other two rotate horizontally and contact the top and bottom surfaces. The teeth are held in slots by adjustable keys, so that damaged incisors may be replaced, and, within limits, the pattern may be

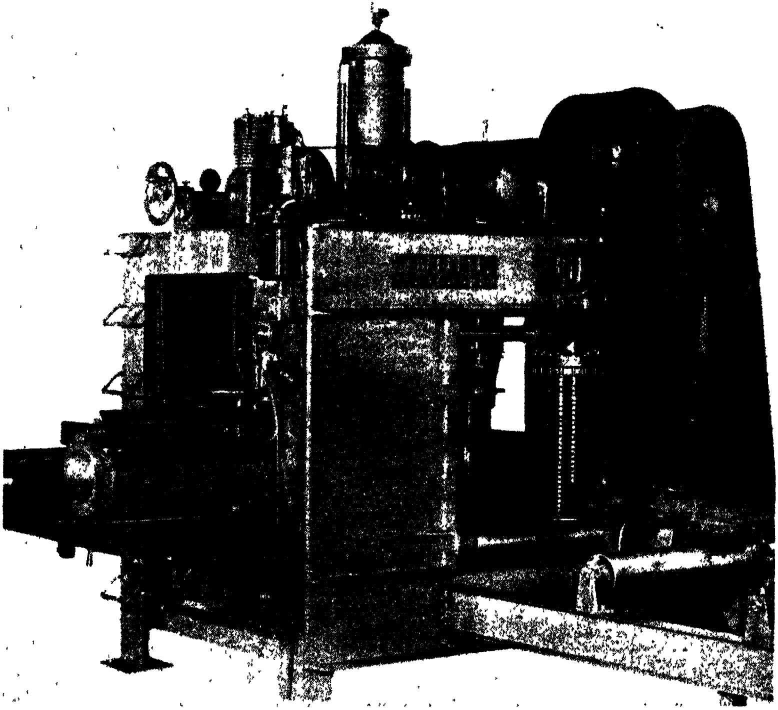

FIG. 45.—Pneumatically controlled incisor for lumber, ties, and timbers. The machine is adjustable for sawed material varying in size from 2 to 26 in. in thickness and from 4 to 30 in. in width. Only one of the four incising rolls is visible. (*Greenlee Bros. and Co.*)

changed if desired. The drums are held against the wood by strong springs and are adjustable for different widths and thicknesses of timber. The material passes through the machine at the rate of about 100 lin. ft. per minute.

Two styles of teeth are in common use (Fig. 46). The "chisel-point" tooth has the advantage of cutting the fibers of the wood over a minimum width of ⅛ in. across the grain to the full depth of the incision. Its chief disadvantages are the rather severe laceration of the wood that results and the large hole that it leaves. The "oyster-knife" tooth has no cutting edge across the grain and, according to some of its proponents, merely spreads the fibers apart without severing them. If this were true, the operation would be of little value, for it is only by exposing the end grain of the wood that incising can be effective in facilitating longitudinal penetration. Actually, the oyster-knife tooth cuts, tears, or crushes enough fibers to expose considerable end grain. However, the hole that it leaves is tapering and consequently not so wide at the bottom as that left by the chisel-point tooth. If it can be shown that the oyster-knife tooth results in as good penetration as the other type, it is to be preferred, since it causes less visible damage to the timber (Fig. 47). The relative depth and uniformity of penetration obtainable in wood incised by the two styles of teeth are now under study by a committee of the American Railway Engineering Association.

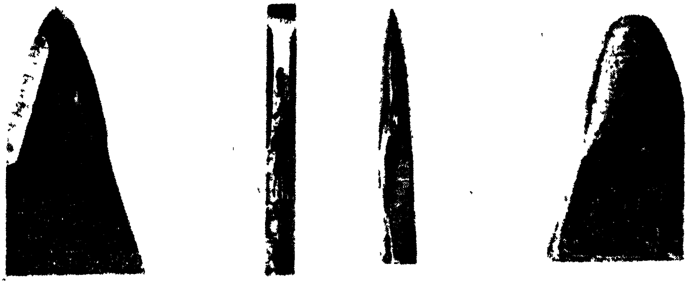

FIG. 46.—Close view of "chisel-point" teeth (left) and "oyster-knife" teeth (right). (*Greenlee Bros. and Co.*)

In the United States, the practice of incising poles has been confined to cedar. Early experiments with chestnut indicated that this species does not greatly benefit from incising, while pine poles with their thick, penetrable sapwood treat satisfactorily without it. Even on round Douglas fir timbers, the sapwood is thick enough and sufficiently penetrable (when pressure treated) to obviate incising. Western red and northern white cedar, however, have a thin sapwood which may be fairly resistant to penetration, especially when the wood is thoroughly seasoned. Consequently, when poles of these species are butt treated by the commonly used hot-and-cold-bath process, the penetration is likely to be erratic and generally insufficient unless the timbers are incised to the approximate depth of the sapwood.

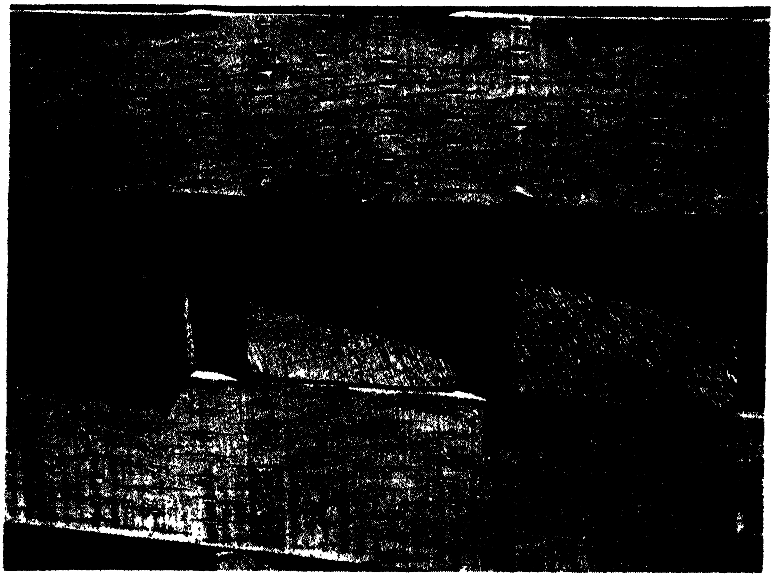

FIG. 47.—Incised hardwood ties, showing incisions made by "oyster-knife" teeth (upper) and "chisel-point" teeth (lower). (*Greenlee Bros. and Co.*)

Because of their round form and irregular surface, poles cannot be incised in the type of machine that is used for ties and other sawed products. The Kolossvary patent, referred to on page 159, was intended primarily for incising poles but apparently was never used commercially in the United States for that purpose. After some use of nail-studded belts or heavy hammers fitted with incising teeth, a practical incising machine was built in 1920 (10) by the Western Cedar Pole Preservers, at Sand Point, Idaho, and subsequently patented (U.S. pat. 1,440,893, Jan. 2, 1923). In this, the pole was revolved slowly around its axis, while a series of heavy bars, extending the length of the ground-line area and each fitted with a single incising tooth, was raised by cams and allowed to drop upon the surface of the timber. The end area of each incising bar was small, so that the teeth could be spaced as closely as was necessary to insure adequate treatment. Each drop of the line of bars incised a narrow strip, after which the pole was turned to present a new surface, the operation continuing until the entire ground-line area was covered. The incising pattern used with this machine is shown in Fig. 44. The normal depth of the incisions was ½ in., which is the approximate thickness of the sapwood in western red cedar, but it varied to some extent because of the occasional knots and other irregularities in the surface of the pole.

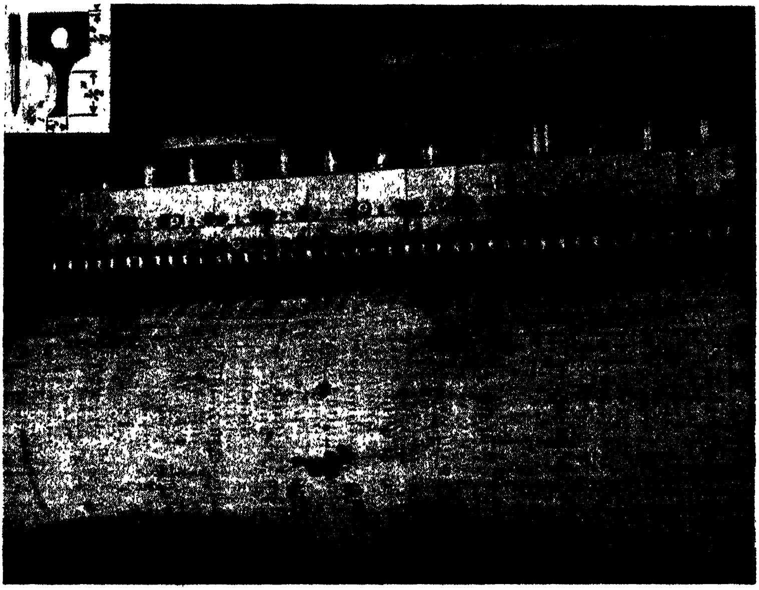

FIG. 48.—Close view of cedar pole in incising machine, and detail of incising tooth used. (*Valentine Clark Corp.*)

Since the construction of the first pole-incising machine at Sand Point, numerous improved machines have been built (Fig. 48). These vary somewhat in detail, shape of incising teeth, incising pattern, and method of operation, but in a general way they follow the principles established by the first machine. The incising of cedar poles is now covered in a specification (No. 43*b*) of the American Wood-Preservers' Association (2), which stipulates that:

> All poles shall be incised throughout that portion of the pole surface terminating 1 foot above and 2 feet below the standard ground line indicated in paragraph 7. The sapwood shall not be splintered nor loosened from the heartwood by the incising operation. The incisions shall be reasonably cleancut to a depth of $\frac{3}{8}$ of an inch or $\frac{1}{2}$ of an inch as stipulated by the purchaser. A variation of $\frac{1}{32}$ of an inch in the depth of the incisions shall be allowed. The pattern and spacing of the incisions shall be such as to insure a uniform depth of penetration of the preservative throughout the incised area.

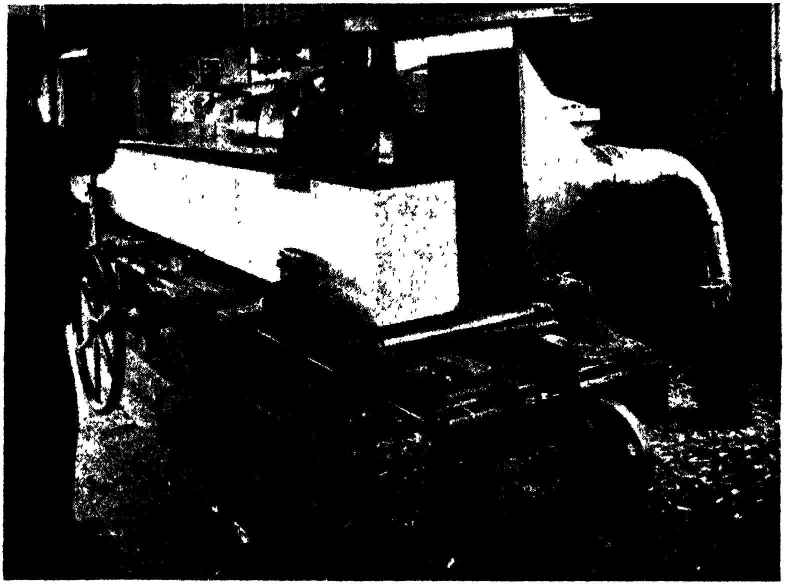

Fig. 49.—Framing (dapping) timbers before treatment.

PREFRAMING

Well-equipped treating plants are now provided with framing mills (Figs. 49 and 50), so that they can shape the most complicated structures and, if desired, fit the individual pieces together before treatment. The pieces can then be numbered, dismantled, treated, shipped to the building site, and reassembled

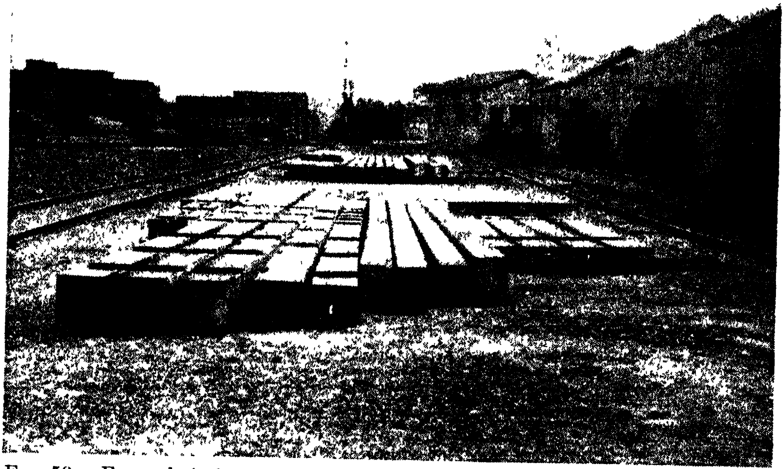

FIG. 50.— Framed timbers. Note framing mill at right. (*The Wood Preserving Corp.*)

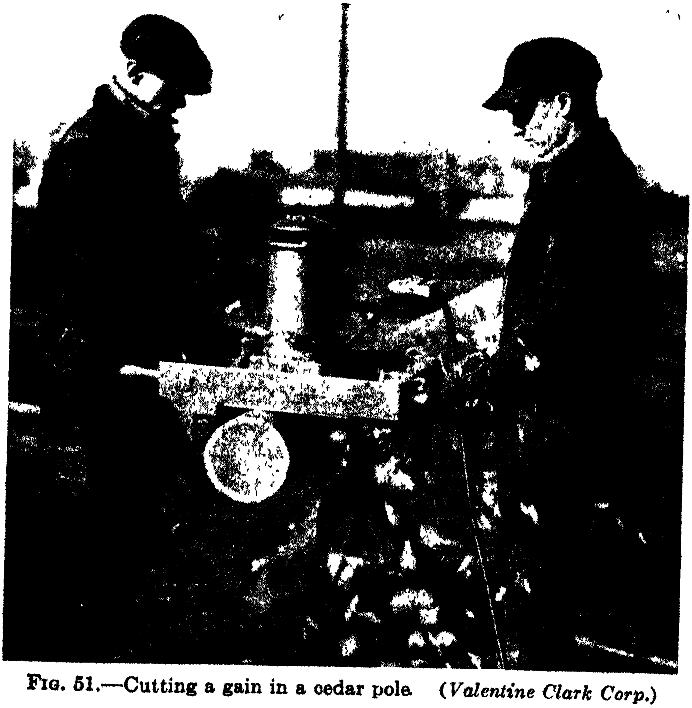

FIG. 51.—Cutting a gain in a cedar pole. (*Valentine Clark Corp.*)

without any further cutting, as is done with a steel structure. The framing mills comprise a series of machines which are designed for boring, cutting, dapping, planing, and any other operation necessary to fashion each piece of wood to the final shape and dimensions required in the finished structure. These machines are arranged in the mill in such sequence and position as will permit the most orderly, efficient, and economical handling of the timber. Portable machines are in common use for gaining (Fig. 51) and boring (Fig. 52) tops of poles.

The framing of timber before treatment is much more feasible than is commonly supposed, and it is widely practiced by railway companies and other important users of treated timber. Highway bridges (19), railway structures (21), barges, and various other forms of construction, for which detailed working drawings can be prepared, are now usually framed before being treated. Machine framing at a mill is usually less expensive than hand framing at a building site.

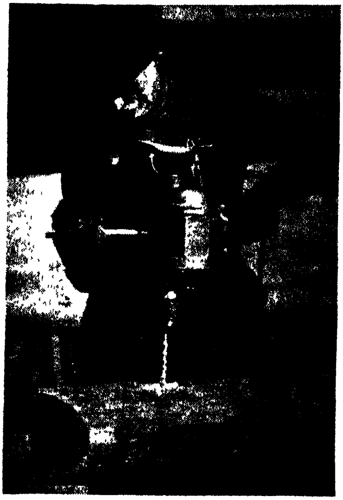

FIG. 52.—Boring cedar pole for crossarm bolt. (*Page and Hill Co.*)

Preframing should materially increase the life of timber used under conditions conducive to decay, since there is then no danger of untreated wood being exposed by cuts made through the impregnated zone. When cutting or boring has to be resorted to on the job, any unprotected wood that is disclosed should be treated as thoroughly as possible. End cuts can usually be impregnated with some degree of success by repeatedly brushing or spraying the wood with preservative, but it is very difficult, if not impossible, to obtain adequate penetration on side-cut surfaces, such as in mortises and daps, with any such superficial treatments. (See discussion of direction of penetration of preservatives, Chap. VII.) Holes that must be bored after treatment should be filled with a hot preservative oil or, preferably, treated under pressure (see page 220 and Fig. 61).

STEAM CONDITIONING

When it is either impracticable or undesirable to air season southern pine timber before applying a pressure treatment, a steaming-and-vacuum process is commonly employed to condition the wood. This involves steaming the timber in the treating cylinder for several hours, usually at 20 lb. gauge pressure, following which a vacuum is drawn on the charge for an hour or more. This results in some loss of moisture from green timber and apparently has other effects, not well understood, which cause the wood to take suitable treatment, even though its moisture content is still relatively high. Partially, or even thoroughly, seasoned material may also be subjected to such treatment, especially when it is desired to sterilize the wood by heating. Although its present use is limited almost entirely to southern pine, steam-and-vacuum conditioning is also applicable to many other softwood species.

In the past, steam pressures as high as 100 lb. per square inch (338°F.) have been used for both southern pine and Douglas fir, and pressures of 25 to 35 lb. have been common. The *Colman method* of steaming Douglas fir piles employed pressures of from 50 to 100 lb. for 3 to 8 hr., and the subsequent vacuum was held for 7 to 14 hr., during which time the cylinder was kept hot. Such very severe heating seriously damaged the wood,* and the method was discontinued. Douglas fir is seldom steamed at the present time, although, when the species is treated with preservatives that cannot safely be heated to high temperatures, such as chromated zinc chloride and Wolman salts, some plants employ a mild steaming process to heat the wood and thus make it more receptive to the subsequent impregnation of preservative. In such cases, the steam pressure, which is not allowed to exceed 10 lb. per square inch (240°F.), is maintained for not more than 6 hr. and followed by a 15- to 60-min. vacuum. In steaming southern pine, it is now considered best practice not to exceed 20 lb. pressure (259°F.), and the specifications of the American Wood-Preservers' Association so provide. Some plant operators raise the steam pressure gradually, reaching the maximum at the end of 1 or 2 hr.; while others attain the full pressure as quickly as possible, apparently with no ill effect.

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* The effect of steaming on the strength of wood is discussed on p. 308.

There is no loss of moisture from the wood during the steaming operation; on the contrary, the water content is actually increased, owing to the condensation of the steam on the surface of the timber. Rapid expulsion of moisture from the timber begins, however, as soon as the pressure is released, partly owing to the expansion of the steam in the wood and partly because the moisture contained in the timber is at a temperature considerably above the normal boiling point of water (16), thus causing it to evaporate rapidly. The subsequent application of a vacuum materially lowers the boiling point (Fig. 54) and thus speeds up the evaporation. As soon as the surplus of heat near the surface of the wood has been absorbed in evaporating moisture, however, the rate of vaporization falls off, and it continues to decrease as the wood cools. In fact, most of the evaporation takes place during the first hour of vacuum. According to MacLean (14), when steamed, green, round, southern pine timbers are subjected to a 5- to 6-hr. vacuum, from 50 to 60 per cent of the total water removed from the wood is taken out during the first hour, from 70 to 80 per cent during the first 2 hr., from 82 to 88 per cent in 3 hr., and from 90 to 95 per cent in 4 hr. There seems to be little, if any, advantage in continuing the vacuum for more than 2 hr.; actually, such a practice may be disadvantageous, since the cooling of the wood will tend to decrease the penetration of the preservative that is to be injected into the timber.

Experiments conducted at the U.S. Forest Products Laboratory (17) have indicated that the repetition of several alternate steaming and vacuum periods of suitable relative length may be more effective in removing moisture than a single succession of steaming and vacuum extending over the same total time. Apparently, there has been no commercial application of this principle, however.

Steaming and vacuum treatments, on the average, remove some 5 to 6 lb. of water per cubic foot of wood from green, round, southern pine timber that is largely sapwood; smaller amounts are obtained from sawed material, especially if it contains a high proportion of heartwood. Little, if any, water will be withdrawn from partially seasoned wood, although the absorption and penetration of preservatives may be definitely improved; with thoroughly seasoned wood the moisture content is often actually increased, but the subsequent impregnation may not be noticeably impaired.

The lengths of steaming periods best suited for different sizes of timber have never been determined, and those actually used in commercial practice vary over wide limits, as shown in Table VII.

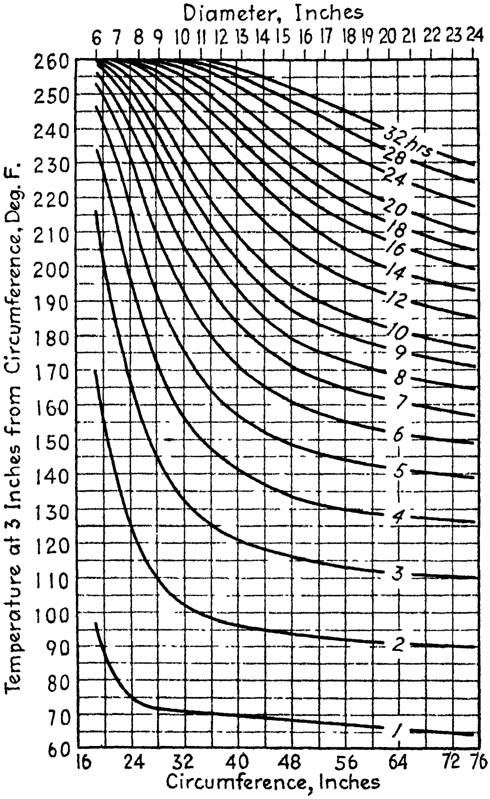

FIG. 53.—Temperatures at 3 in. from the circumference in round, green, southern pine timbers of different dimensions, steamed at 260°F. (approximately 20 lb. gauge pressure) for the time indicated on the curves. Initial temperature of wood taken as 60°F. (*U.S. Forest Products Laboratory.*)

The improvement in absorption and penetration resulting from the steam-and-vacuum conditioning of partially seasoned timber is apparently brought about by the increased temperature imparted to the wood during the steaming period, since the moisture content is not greatly reduced. The temperature within the wood usually remains high, unless the vacuum is continued too long. The lack of uniformity in commercial steaming practice may probably be attributed, in large measure, to the dearth of information on these wood temperatures. MacLean (14, 16) has done much to clarify the subject and bring

TABLE VII.—STEAM-AND-VACUUM TREATMENTS USED AT VARIOUS PLANTS TREATING GREEN SOUTHERN PINE, 1930–1931 (14)

Plant number	Material	Steam pressure, pounds per square inch	Steam period,* hours	Vacuum period after steaming, hours
1	Poles and piling	30	8 to 10	2
	Sawed timber	30	7 to 10	2
2	Poles	27	7 to 10	3
	Piling	27	8 to 12	3
3	Poles	20	8	3
4	Poles and piling	20	7	1
	Crossarms	15	5	1
5	Poles and piling	30	10 to 12	2
	Sawed timber	30	10 to 12	2
	Crossarms	20 to 30	8	2
6	Poles and piling	20 to 30	8 to 12	2 to 2½
7	Poles and piling	20 to 40	6 to 14	3 to 4
8	Poles	35 to 40	8	3 to 4
	Piling	30 to 50	12 to 15	6
9	Poles and piling	20 to 30	12 to 14	4
10	Poles and piling	15 to 20	8 to 10	3 to 4
11	Poles and piling	20	12 to 14	2 to 2½
12	Poles and piling	20	6 to 12	1
	Sawed timber	20	4 to 12	1
13	Poles and piling	20	6 to 8	2
14	Poles and piling	25 to 30	6 to 10	4
	Sawed timber	25 to 30	8 to 10	3 to 4
15	Poles and piling	25 to 30	8 to 10	2
	Crossarms	25 to 30	5	1
16	Poles	20 to 25	8 to 19	1
17	Poles and piling	30	6 to 16	3 to 4
	Sawed timber	30	6 to 10	2 to 3
18	Poles and piling	25 to 30	8 to 14	2
	Sawed timber	25 to 30	8 to 10	2
19	Poles and piling	20	6 to 12	2
	Sawed timber	20	8 to 10	2
	Ties	20	4	1 to 1½
	Wood conduit	15	5	2
20	Poles and piling	20 to 30	10 to 12	3 to 4
	Sawed timber	20 to 30	8 to 10	4
21	Poles and piling	15	6 to 8	1 to 2
	Sawed timber	15	5 to 6	1 to 2
22	Poles and piling	20	5 to 10	3
23	Poles and piling	20	10 to 12	2
24	Land piling	20	14	2
	Marine piling	30	15	1
25	Piling	30 to 35	8 to 15	2
	Sawed timber	25 to 30	6	2
	Conduit	15 to 20	2	1
26	Piling	20 to 25	8 to 12	2
	Sawed timber	20 to 25	5 to 10	2
	Crossarms	10 to 15	5 to 6	1½ to 2

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* Steam pressures are usually applied gradually, and the maximum is reached in from 1 to 2 hr. The periods given are for the time of steaming after the maximum steam pressure has been obtained.

about improved steaming practice, by determining the actual temperatures that are attained in timbers of different sizes and conditions, when subjected to various steaming treatments. By means of MacLean's curves and formulas, it is possible to calculate the temperature to be expected at any depth below the surface of a southern pine timber under any given steaming period and pressure.

Figure 53 shows the temperatures that are reached at 3 in. beneath the surface in green, round, southern pine timbers of different diameters and under the conditions named. With the help of these and similar curves, the problem of determining suitable steaming periods can be worked out gradually, even though it is not yet known just what temperature should be attained for best results. For example, a tentative schedule of steaming periods for different sizes can be prepared on the assumption that a satisfactory wood temperature is 200°F. at 3 in. below the surface of southern pine timbers. By careful observation of the results obtained by following this schedule, it can be determined in the course of time whether a milder or more severe schedule is desirable, and changes can be made accordingly. Excessive steaming must be avoided, of course, for it will seriously damage the wood. As a general principle, steaming should be as mild as is consistent with good absorption and penetration.

The general treating procedure that follows the steaming-and-vacuum period is dependent upon the type of process to be employed. When the timber is to be impregnated by the full-cell process, using either preservative oils or water solutions, the vacuum following the steaming also serves as the initial vacuum of the regular treatment, and the preservative is immediately admitted into the cylinder. With the empty-cell treatments, on the other hand, it is necessary to break the poststeaming vacuum and then admit the oil (Lowry process) or apply the desired initial-air pressure (Rueping).

STEAM AIR-PRESSURE CONDITIONING

Patents have been issued to F. S. Shinn (U.S. pats. 1,687,900, Oct. 16, 1928; 1,763,070, June 10, 1930) covering two methods of conditioning green wood by the application of air pressure, in addition to steaming and vacuum. A typical procedure under the first patent is to steam the wood in the treating cylinder at 20 lb. pressure for an hour, follow this with a high 1-hr. vacuum, and then apply air at about 80 lb. pressure for an hour; at the end of the period, the pressure is released suddenly. It is claimed that part of the water in the green wood is removed in the form of vapor during the vacuum treatment and that an additional amount of moisture is subsequently brought out in liquid form by the sudden release of the air pressure. The cycle of treatments can be repeated if further reduction in the moisture content of the timber is necessary. The second of the two patents covers a modification of the foregoing process, in which the air pressure is applied immediately after the steaming period and before the vacuum. Little is known as to the effectiveness of these methods, in comparison with straight steaming-and-vacuum treatment, and neither of them has found extensive use.

BOILING UNDER VACUUM

A method of conditioning green wood for treatment, by boiling it in coal-tar creosote while the charge is under vacuum, was devised by S. B. Boulton and patented in 1879 in England and in 1881 in the United States (U.S. pat. 247,602). The first mention of such a treatment appears to have been made by John Bethell (Brit. pat. 7731, July, 1838), but he apparently did not develop the idea to any extent. The Boulton method is now extensively employed on the Pacific coast, in the treatment of Douglas fir, and also finds some use in other parts of the country for conditioning this and certain other species. In carrying out the treatment, the green wood is placed in the treating cylinder and submerged in hot oil, the temperature of which is maintained while a vacuum is gradually applied. Since the boiling point of water is lower under a partial vacuum than at atmospheric pressure (Fig. 54), drying can proceed rather rapidly even at temperatures below 212°F. As a result, the wood can be conditioned for treatment by the Boulton method at temperatures considerably below those required in the steaming-and-vacuum process. This is of great advantage with woods that are easily damaged by high temperatures, such as Douglas fir and many of the hardwoods. The treating procedure that follows the conclusion of the boiling-under-vacuum period depends upon the impregnation process to be used. If the full-cell treatment is to be given, additional oil is admitted to fill the cylinder, and the necessary pressure is then applied to force the preservative into the wood. On the other hand, when an empty-cell treatment is to be used, the oil must first be drained from the cylinder, and air admitted; the treatment then proceeds by the regular Lowry or Rueping process, as desired. While originally intended for use with straight coal-tar creosote, the boiling-under-vacuum process can also be employed with creosote mixtures or any preservative oils that will not foam or cause other trouble during the conditioning period. It is entirely unsuitable for water-soluble preservatives, however, since the water in the solution would evaporate even more readily than that in the wood.

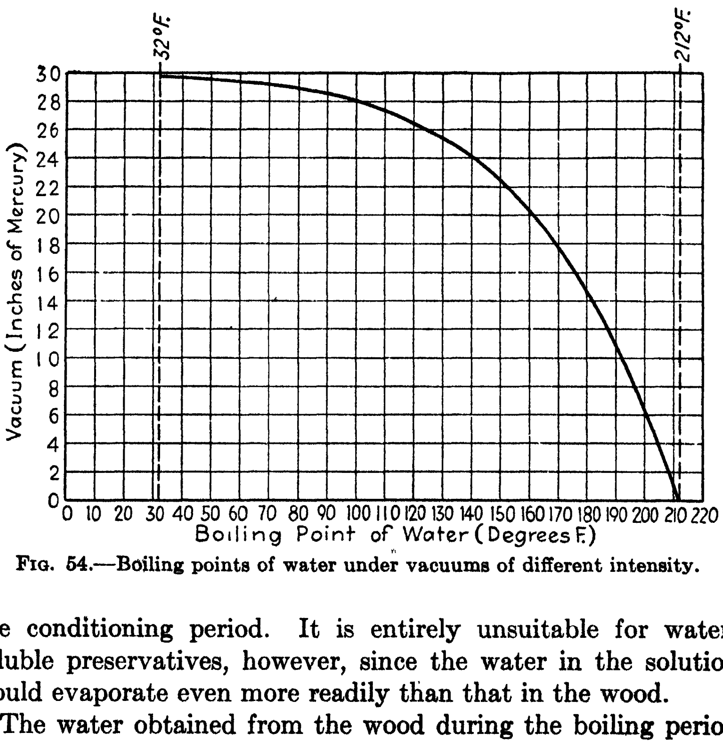

FIG. 54.—Boiling points of water under vacuums of different intensity.

The water obtained from the wood during the boiling period passes through a condenser and is collected in a receiver, so that it can be weighed or measured. A certain amount of light oil usually evaporates from the preservative and collects in a layer on top of the water in the receiver, but this can be drawn off and returned to the preservative supply. The rate of evaporation of moisture is slow while the wood is being heated to the boiling point, speeds up as the surface and outer layers of the timber give up their water, and then gradually slows down again as the drying proceeds deeper into the wood.

The amount of water removed from the wood depends on the size and shape of the timbers, their moisture content, the proportions of sapwood and heartwood, and the temperature and vacuum conditions employed. Since unseasoned sapwood usually has a higher moisture content and is also more permeable than heartwood, more water per cubic foot of wood is obtained from round material (poles and piles), with its enclosing sheath of sapwood, than from sawed timbers in which the faces are largely heartwood. More water per unit volume is also evaporated from small pieces than from large timbers of the same kind and quality of material, because the former have a greater surface area per cubic foot. In laboratory experiments made on Douglas fir with the Boulton process, MacLean (15) found moisture losses as low as 1 lb. per cubic foot of wood in green all-heart timbers and as high as 9 lb. in round pieces having relatively thick sapwood. In these experiments, the ends of the pieces were tightly covered. In some round timbers, the moisture content of the entire sapwood (up to 1.2 in. in depth) was reduced below the fiber-saturation point; in the all-heart specimens, this point was usually attained only in the outer ½ in. of wood, and there was very little drying at more than 1½ in. below the surface. Rawson (20) reported somewhat greater moisture losses than the foregoing in actual commercial treatments. This may be explained, in part, by the fact that the end surfaces of the timbers were exposed, a condition that would make a noticeable difference in ties and other products having a relatively high ratio of end-to side-surface area. It might also be accounted for if the timber contained a high proportion of sapwood or had been stored in water or rained upon just prior to treatment. Larger amounts of water can be removed by the Boulton process from southern pine or red oak (14) than from comparable Douglas fir timbers.

The present specifications (38*a*, 41*a*, and 45*a*)* of the American Wood-Preservers' Association require that, in conditioning

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* These specifications are now being revised and some changes in requirements are anticipated.

Douglas fir lumber and sawed timbers by the Boulton method, the temperature of the preservative oil during the boiling-under-vacuum period shall be not less than 180°F. or more than 200°F.; in the treatment of Douglas fir piles and crossties, the temperature is allowed to attain a maximum of 220°F. The vacuum during the boiling period is required to reach not less than 20 in. In practice, the vacuum is built up gradually during the first part of the process and may not reach the specified minimum for several hours. This is necessary, since the sudden application of a high vacuum would cause such rapid boiling that the oil might surge over into the vacuum line.

It is generally preferable to use the minimum, rather than the maximum, specified temperatures, and the boiling should continue for only as long a period as is necessary to prepare the timber for the subsequent impregnation of preservative. Even though this is a milder conditioning process and consequently less harmful to the wood than steaming, high temperatures and long boiling periods can materially reduce the strength of the timber. The specifications referred to require that the boiling be continued until the rate of evaporation is reduced to $\frac{1}{10}$ lb. of water per cubic foot of wood per hour. In view of the wide variations in the ratio of surface area to unit volume in different sizes and shapes of timber, such a rule does not seem very logical, and, in fact, it is not followed closely in practice. A more reasonable procedure would be to use the surface area of the timber, rather than its volume, as the basis for determining the end point. The range of boiling periods and temperatures commonly used in commercial practice is reported by MacLean (14) as about 8 to 16 hr. at 180 to 200°F. for ties, bridge timbers, and lumber and 35 to 60 hr. at 190 to 220°F. for poles and piles. Temperatures in excess of 220°F. are reported occasionally.

Studies at the U.S. Forest Products Laboratory (15) have shown that the temperature of green Douglas fir timbers heated in creosote increases at about the same rate as that of green southern pine timbers subjected to steaming at the same temperature. If the moisture could move freely in the wood and evaporate rapidly, the temperature of the Boulton-processed timber would rise no higher than that of boiling water at the prevailing vacuum. Actually, it rises much higher. This is due, no doubt, to the slowness with which the moisture moves toward the surface of the wood as well as to the fact that, in Douglas fir, the vacuum does not "penetrate" deeply into the heartwood. It has been observed that a pressure of several pounds per square inch may be built up at the center of a heartwood stick, as a result of the heating and expansion of the air in the wood, even though a high vacuum has surrounded the timber for several hours. MacLean (15) found, in some instances, that the temperature at the center of heartwood timbers rose to about as high a point when the wood was heated in creosote under vacuum as it did when no vacuum was applied, gradually attaining the temperature of the oil in both cases. In other timbers, the wood temperature rose to within 5 to 10°F. of the oil temperature and then remained practically constant. This latter result is apparently attributable to the greater permeability of these individual pieces and the more rapid evaporation of the water that they contained.

Although the process of boiling under vacuum is used mainly in the treatment of Douglas fir, it is also adaptable to other species of wood. It has been used commercially and with good success for conditioning red oak piles and bridge timbers and has also been employed to some extent, both commercially and experimentally (13), in the treatment of southern pine poles. In readily penetrable woods, such as red oak and sap southern pine, however, it is difficult to get good penetration with a low absorption of preservative after boiling under vacuum, because the timbers take up too much oil before the pressure period begins. Most of this preliminary absorption probably takes place after the vacuum has been discontinued, while the oil is being drained from the cylinder in preparation for the empty-cell treatment; it is apt to be particularly high, if air pressure is applied to the cylinder to hasten the draining of the preservative. Since this preliminary absorption takes place under practically full-cell conditions, it does not penetrate so deeply as it should. In 8- or 10-lb. empty-cell treatments of green southern pine poles or piles, better penetrations can be obtained when the timber is conditioned by steaming and vacuum than when it is subjected to the boiling-under-vacuum process. With higher absorptions, however, excellent penetrations may be obtained by either conditioning method.

BOILING WITHOUT VACUUM

A method of boiling green wood in creosote at atmospheric pressure was patented in 1895 (U.S. pat. 545,222) by William G. Curtis and John D. Isaacs and used for some years in the treatment of Douglas fir on the Pacific coast. The temperatures used in this conditioning treatment were excessively high, sometimes reaching 250°F. Considerable checking of the wood often occurred, with a consequent serious reduction in the strength of the timber; one series of tests (22) showed strength losses of as much as 34 per cent. The boiling method of conditioning has been entirely replaced by the milder boiling-under-vacuum process.

FANNING

The fanning treatment for conditioning unseasoned wood was developed about 1932 by J. B. Card and is now being used to some extent by one railway company in the treatment of green red oak ties. As practiced at one plant, the procedure is as follows: After the ties are placed in the cylinder, they are heated in creosote at atmospheric pressure for about 6 to 7 hr.; the oil temperature is gradually raised to 180°F. during the first 3 or 4 hr. and then held at that point for the remainder of the period. The oil is then drained from the cylinder, and a powerful fan, operating in a large air pipe, is used to circulate heated air through the cylinder for about 7 hr. During the fanning period, the steam coils in the cylinder are kept hot, and additional heat is supplied to the air in the circulating system. At the outset, the air temperature is about 160°F., but it is allowed to drop gradually to 135 to 140°F. toward the end of the period. In passing over the hot wood, the air takes up the water vapor that is given off by the material and tends to become more or less saturated; in order to maintain the drying conditions, part of the moisture-laden air is allowed to escape, being replaced by fresh air at the fan. At the conclusion of the fanning period, the wood is impregnated with creosote by the full-cell or empty-cell method, as may be desired.

It is claimed that the moisture content of the wood can be rapidly reduced by this method, without causing serious checking of the timber, and that freshly cut red oak ties conditioned in this manner can be given a thorough creosoting treatment. However, the method has not been investigated sufficiently to establish clearly its advantages and limitations.

KILN DRYING

Kiln drying is very seldom employed in preparing wood for preservative treatment, since most structural timber is too large in size to be dried economically in this way. Exceptions to the general rule are to be found in window sash, doors, flooring, furniture, automobile parts, finish lumber, and other specialized items that are to be treated with nonaqueous preservative solutions. However, such products as these are kiln dried to avoid subsequent shrinkage troubles and not for the purpose of facilitating treatment. The kiln may also be used as a means of heating dry wood that is later to be submerged in a tank of cold preservative solution (U.S. pat. 1,991,811, Feb. 19, 1935, to F. H. Lyons). If an inexpensive and otherwise practical method could be devised for kiln drying large material, it might be adopted to advantage in those sections of the country where blue stain and storage rots are serious hazards during air seasoning.

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CHAPTER VI

WOOD-PRESERVING PROCESSES

Although there are no records of the first attempts made to protect wood from decay and insect attack, it is reasonable to suppose that they consisted of merely brushing or rubbing the preservative materials over the surfaces of the timbers to be protected. It is an easy step from these practices to dipping and soaking methods, and such treatments are doubtless of very long standing. Charring the surface of the wood was also unquestionably resorted to at a very early date.

Inventors working in the field of wood preservation have been almost as busy attempting to devise new and better methods of injecting toxicants into timber as they have been in trying to discover new preservative materials. Because of its porous structure, wood might be expected to be very easy to treat, but, as a matter of fact, it offers surprising resistance to penetration by liquids. The ingenuity of the inventors has been severely taxed in the effort to devise treating processes that will give the deep and uniform penetration desired without damaging the wood or using too much preservative. The use of artificial pressure was not tried until early in the nineteenth century, after the invention of suitable equipment made possible the application of such force. The development of the modern impregnation processes began in earnest in the outstanding decade of activity, between 1830 and 1840, when Bethell, Boucherie, Burnett, and Kyan were making wood-preserving history. Since that time, innumerable processes have been introduced, but most of these have never been employed commercially. Many woods are being effectively treated at moderate cost by the methods now in use, but some species are very resistant to impregnation, even when subjected to the best of the modern processes. No one has yet discovered a practical means of insuring deep penetration in all woods at reasonable cost.

The treating methods most extensively employed today are those that have demonstrated their value (and limitations) during many years of use. New processes are constantly promoted, in the hope of demonstrating their superiority over the accepted methods or of finding some special field of application. Occasionally a new treatment is found useful, but most of them do not prove to be commercially successful. Extravagant claims are made for many of these treatments, especially as to the depth of penetration that may be obtained. It is interesting to note that many of the processes introduced as new are merely old discarded methods that have been revived, sometimes with modifications and improvements but often without change.

The protection afforded by any method of applying preservatives depends primarily upon its ability to secure deep and reasonably uniform penetration. As a general rule, the cheap, simple methods give only superficial penetrations and light absorptions, and hence are low in effectiveness. They may serve when circumstances prevent the use of better processes but should be supplanted by the more thorough methods whenever possible. The low initial costs associated with the simple treatments do not necessarily insure real economy in wood use. The lowest cost per year of actual service is most likely to be attained by thoroughly impregnated timber, even though the treating charges may be comparatively high.

Most of the wood-preserving methods now in use may be classified roughly as either *nonpressure processes,* which are carried out without the use of artificial pressure, or *pressure processes,* in which the wood is placed in a treating cylinder or retort and impregnated with preservative under considerable force. There is also a third group of miscellaneous processes, in which the wood is treated in one way or another and under slight to moderate pressure but not in a closed cylinder. These three groups are dealt with separately in the following pages. Because of their variety and the widespread interest in them, considerable space is devoted to the nonpressure processes. It should be kept in mind, however, that all but a small percentage of the wood treated annually is impregnated by pressure methods in closed cylinders. The amount of space given to the individual processes is not an indication of their respective importance.

NONPRESSURE PROCESSES

The nonpressure processes of treating wood are numerous and quite varied in their procedure. The more widely recognized of these treatments involve the application of preservatives by brushing or spraying, dipping, steeping (including Kyanizing), or the hot and cold bath. In addition to these more or less standard methods, there are a number of miscellaneous nonpressure processes which have been used from time to time. Some of them, such as charring, applying preservatives in bored holes, setting timber in stones or concrete, and treating standing trees, were originated many years ago. The others, most of which are patented, may be classified as either charring and spraying treatments or diffusion processes.

BRUSH AND SPRAY TREATMENTS

The processes included under this heading provide for brushing or spraying preservative over the surface of the timber to be treated. Some of the liquid is drawn into the wood as the result of capillary action, but the penetration is usually very slight, at best. The superficiality of treatment is largely attributed to the natural resistance that wood offers to penetration, but it is also influenced by the small amount of preservative applied.

Coal-tar creosote and similar oils* are the preservatives generally employed in brush or spray treatments, but water-soluble salts are also used to some extent. The oils, as a class, are more resistant to leaching than preservatives applied in water solution and, therefore, should give somewhat longer protection to wood that is exposed to wet conditions. This reasoning may not be valid for water-borne chemicals that form a precipitate of low solubility after they are applied to the wood. The penetration obtained with either type of preservative is so shallow, however, that only very limited protection may be expected under conditions favoring rapid decay. The zone of treated wood is easily broken through by subsequent abrasion or checking, with the result that untreated wood is exposed to fungus or insect attack. The quantity of preservative available per unit of surface area is also so slight that, when the wood is exposed to the elements, it may be reduced rather rapidly below the point of effectiveness. Thorough brush or spray treatments with coal-tar creosote may be expected to add from 1 to 3 years to the life of poles or posts.

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* Special creosotes or anthracene oils which are liquid even at 32°F. are recognized in the specifications of the American Wood-Preservers' Association for preservatives for brushing or spraying (p. 106). The ordinary grades of creosote are also acceptable, although they may require melting in cold weather.

In using the brush or spray methods, the preservative should be flooded over the surface of the timber and allowed to soak into the wood as much as possible; it should not be brushed out thin, like paint. All checks and other openings should be filled as thoroughly as possible. Two coats provide much better protection than one, but the second coat should not be applied until the first has dried or soaked into the wood. It is considered advisable to heat preservative oils before applying them. The wood should be thoroughly air seasoned before treatment and also warm enough to avoid any marked tendency toward thickening or congealing of the oil. It is useless to brush or spray oils upon wood that is green or frozen or that has recently been wet by storms. The same precautions should be observed when using water solutions, although preservatives of this type can diffuse into green or wet wood, while oils cannot.

A modification of these superficial treatments consists of *pouring* the preservative on the wood. The timbers are skidded or placed over a tank of hot creosote, and the preservative is poured over them by means of a long-handled dipper, the excess liquid draining back into the tank. The results obtained with this method are said to be comparable to those secured by brushing or spraying, but more expensive equipment is required, so that there seems to be little justification for its use.

In the processes under consideration, the circumstances attending the actual use of the timber will determine whether the application of preservatives should be made over the entire surface of the wood or confined to certain localized areas. For example, mud sills, floor joists, and other products, which are laid on the ground or used in such other ways that decay may gain a foothold at practically any place, should be treated over their entire length and on all surfaces. On the other hand, posts and poles of durable or moderately durable wood are subject to deterioration chiefly at the ground line, and treatment is largely confined to the butt ends of the timbers. Many timbers, used in bridges, trestles, and certain types of buildings, will be exposed to marked decay hazard only at joints, surfaces of contact with one another, or at other localized points, and protection may be needed only at such locations, although full-length treatment would undoubtedly be advantageous in most cases.

It is of little use to brush or spray a preservative over the surface of timbers already in service in buildings, bridges, and similar structures. The concealed areas, which cannot be reached by the chemical, are usually in greatest danger of decay and termite attack, and the application of preservative to the other parts will not afford any protection to the inaccessible surfaces. Furthermore, such treatment is not even likely to stop attack that may have already become well established on the exposed surfaces. On the other hand, poles and similarly placed timbers may be given some measure of protection against surface decay at the ground line, by digging away the surrounding earth, removing any visibly infected wood, allowing the exposed surface to dry, and then brushing or spraying it with preservative. Sometimes, in the commercial application of this treatment to standing poles, the surface of the wood is sterilized and dried by charring it before applying the preservative. (See charring and spraying treatment, page 192.) In the case of chestnut poles infested with carpenter ants, it has been found practicable to bore into the timbers near the top of the insect galleries and fill the excavations with creosote, or a mixture of creosote and gasoline.

Brush or spray applications are also useful for protecting untreated surfaces, which are exposed by cutting or framing timber after treatment. The degree of protection thus afforded at the cut surfaces may be considerably less than was provided by the original treatment, especially if the wood has been impregnated under pressure, but such applications will be decidedly better than no treatment at all. Brushing and spraying are most effective when applied to end-grain surfaces, since the preservative penetrates much more readily in the direction of the grain (longitudinally) than across it (radially or tangentially). Thus, pile heads, cut to grade after driving, can be very well protected by thorough and repeated brushing with creosote, after which they should be covered with metal or other suitable water-shedding material. Unprotected wood, exposed through the boring of bolt holes, may be treated by filling the holes with preservative or by inserting a nozzle and spraying the liquid into the openings; however, a more thorough treatment is provided by the apparatus described on page 220.

While brushing and spraying are not to be recommended for use when the more thorough treatments are available, these methods of applying preservatives are used rather extensively, because of their marked simplicity and low first cost. The required equipment is portable, so that treatment can be given on the job as well as at concentration points, and the preservative is quickly and easily applied. Furthermore, the methods are applicable to single pieces and small lots of timber as well as to larger scale operations; the amount of preservative required for a given job may be so gauged that little or none of it need be left over.

Dipping

As applied to structural forms of timber, dipping consists in merely immersing the wood in a bath of creosote or other preservative for a short time, usually from 5 to 15 min. It is somewhat more expensive than brushing or spraying, since it requires more equipment and larger quantities of preservative and is not so well adapted to treating small lots of timber, especially on the job. However, it has a definite advantage over these other methods, in that it insures a more adequate penetration of checks and other openings and involves a longer contact between the wood and the preservative. Nevertheless, the degree of protection attained cannot be expected to be greatly superior to that resulting from thorough brush or spray treatments; at best, the penetration will be slight, and the absorption limited. The same general precautions should be observed as in brushing or spraying. For best results, the preservative should be heated, and the wood well seasoned. Dipping is not recommended for wood that will be subject to heavy wear or abrasion in service, but it may add 2 to 4 years to the life of timber that is not used under very severe conditions. The process should be employed only when it is not practicable to use more effective treating methods.

When window sash and similar products are dipped in "clean," nonswelling preservatives (page 123), an immersion period of less than 1 min. is often used, in order to keep the cost as low as possible, although 3 min. is the minimum usually recommended. Such brief contact with the preservative gives appreciable penetration only at joints and other places where the end grain of the wood is exposed. Whether an extremely light treatment of this character will prove economical in the long run remains to be seen; in the case of window sash, it is probable that the increased cost of longer submersion would be more than offset by the added protection given to the wood.

Steeping

This process consists in submerging wood in a tank of preservative, usually a water solution, and allowing it to soak for several days, or even weeks (18). The preservative solution is usually allowed to remain at atmospheric temperature, although more rapid penetration would be obtained if it were heated. When the treatment is applied to seasoned timber, both the water and the preservative salt that it contains soak into the wood. But with green material only a slight amount of water, if any, can enter the wood, and most of the absorption takes place by the diffusion of the salt from the preservative solution into the water already in the timber.

Absorption is most rapid during the first two or three days but will continue at a decreasing rate for an indefinite period. Consequently, the longer the wood can be left in the solution the better treatment it will receive. If the soaking were continued long enough, the absorption and penetration would equal, if not exceed, those obtained in pressure treatments. However, this would require immersion for months, or even years in some cases, and, therefore, is not practical. An old rule of thumb for determining the steeping period for seasoned wood was to allow 1 day for each inch of thickness of the material, with an extra day added for good measure. However, there is apparently no logical basis for such a rule, and a soaking period of a week to 10 days is ordinarily considered desirable.

The absorptions obtained during the customary steeping periods are slight in seasoned timber, and the penetrations generally do not exceed from ⅛ to ¼ in., although they have been known to surpass an inch in sap pine. Because of the low absorptions, it is desirable to have the treating solutions somewhat stronger than those used with pressure processes. For example, a solution strength of about 5 per cent is recommended for zinc chloride. When steeping green timber, practically none of the water of the solution enters the wood, and the concentration decreases as the chemical is absorbed. To provide for this, as well as to promote rapid diffusion, it is desirable to use higher strengths (such as 10 per cent) than are employed for seasoned timber. Better penetrations are obtained in green than in seasoned wood, especially if the former is close piled and allowed to remain damp after being removed from the steeping vat. So long as the timber retains a high moisture content, the chemical will continue to spread within the wood, in accordance with the well-known laws of diffusion. In both green and seasoned material, penetration will be much greater in sapwood than in heartwood.

The wood should be piled in the steeping tank in such a way that the preservative can reach all surfaces. Round posts and poles are so irregular that special separation is usually not necessary. Sawed material, however, should be piled with stickers, ½ in. or more in thickness, between the courses, and spaces should also be left between the sides of adjacent pieces to allow for circulation of preservative and the escape of any air that may come out of the wood. Provision must be made against the floating of the timber. This can be done, either by piling the material in the tank and anchoring it down before admitting the preservative or by sinking the timber in the preservative by means of weights.

Kyanizing.—This treatment is named after John Kyan, who patented it in England in 1832. It is merely a steeping process, in which mercuric chloride solution is used as the preservative. It has been employed for many years in Germany (14) and other European countries for the treatment of poles and has also found some use in the United States for preserving lumber and building timbers. Because of the high toxicity of the mercuric chloride and its resistance to leaching, very good protection may be provided, despite the limited penetration of from ⅛ to ½ in.

The practice in Kyanizing poles in Europe is to soak them for a week to 10 days in a 0.67 per cent solution of mercuric chloride. One modification of the process, called "improved Kyanizing" (11), makes use of a solution containing 0.67 per cent of mercuric chloride and 1 per cent of sodium fluoride. The latter salt is claimed to penetrate deeper than the mercuric chloride and thus to give added protection. Poles are usually air seasoned before Kyanizing, but at some European plants green timbers have been treated by first heating them in steam or in an oven and then submerging them in the preservative while they are still warm.

In the Kyanizing process, it is necessary to use tanks made of wood, concrete, or some other material that will not be corroded by the mercuric chloride. At the Lowell, Mass., plant, which was constructed in 1848 and is still in use, the treating tanks were made of solid granite blocks, laid in Portland cement and coated on the inside with hot tar.

HOT AND COLD BATH

This process, which was patented by C. A. Seeley (U.S. pat. 69,260, Sept. 24, 1867), is also known as the open-tank treatment and the boiling-and-cooling method. It involves the immersion of seasoned wood, for a matter of hours, in successive baths of hot and relatively cool preservative (12, 17). The function of the hot bath is to expand the air in the outer layers of the timbers and to evaporate moisture at the surface; the duration of the bath and the temperature of the preservative will largely determine the extent to which the air and water vapor leave the wood. The cold bath, in turn, causes the air and vapor remaining in the outer shell of the wood to contract, thus forming a partial vacuum. To satisfy this vacuum, atmospheric pressure tends to force the surrounding preservative into the wood. Very little penetration takes place during the hot bath, except in wood that is unusually absorptive. The change in baths may be accomplished in several ways: by transferring the heated wood to a separate tank of relatively cool preservative; by withdrawing the hot liquid from the tank and replacing it with unwarmed preservative, without moving the timber; or by merely discontinuing the heating and allowing the wood and preservative to cool together. In the first two cases, it is imperative that the change be made without undue delay; otherwise, the heated wood will begin to cool in contact with the air, and the effectiveness of the subsequent cold bath will be impaired. The American Wood-Preservers' Association specifications for butt-treating poles stipulate that the period between baths shall not exceed 10 min. The timber to be treated should be rather thoroughly air dried, not only to facilitate penetration but also to eliminate the subsequent extension of seasoning checks through the impregnated shell of wood.

Both preservative oils and water-soluble salts may be applied by the hot-and-cold-bath process, but the great bulk of the treatment is done with coal-tar creosote and mixtures of creosote and other oils. The preservative oils have a definite advantage, in that they afford more permanent protection to poles, posts, and other forms of timber that are to be exposed to the weather, and also because they can be heated to the desired temperatures in open tanks without too much loss by evaporation. When water solutions are employed, the temperatures must be kept below the boiling point, and water must be added occasionally to compensate for evaporation and thus keep the solution at proper strength. A maximum solution strength of 5 per cent is recommended for zinc chloride.

When coal-tar creosote is used, hot-bath temperatures of 210 to 220°F. are usually adequate for general purposes. However, specifications 43*b* and 44*b* of the American Wood-Preservers' Association, covering the butt treatment of cedar poles, stipulates a temperature range of 225 to 235°F. The higher temperatures tend to improve penetration, but they also cause somewhat greater evaporation of oil from the tank; this loss may be considerable with creosotes of relatively low boiling range. The cold bath should be as cool as is consistent with keeping the preservative thoroughly liquid. Temperatures of around 100°F. are about right for preservative oils. The pole specifications previously referred to require that the cold bath shall be "between 150°F. and the temperature at which solids form in the preservative." When water solutions are used, the cold bath can be maintained at atmospheric temperatures, so long as they remain above freezing.

The time of treatment may vary to a considerable extent, depending upon such factors as the species of wood, the type of product, the extent to which the timber has been seasoned, the weather conditions, and often upon the opinion of the person in charge of the operation. Each bath may last from 1 to 12 hr. or even longer. The American Wood-Preservers' Association specifications 43*b* and 44*b* provide for a hot bath of not less than 6 hr. and a cold bath of at least 2 hr.

Woods that are very easily impregnated may require special treatment if the operator is to obtain reasonable penetration without excessive absorption of preservative. To this end, recent work by the Texas Forest Service in treating small shortleaf and loblolly pine poles shows the advantage of reheating such material, following the cold bath (6). When these poles were treated by the usual hot-and-cold-bath method, excellent penetrations (averaging 2 in.) were obtained, but the amount of creosote absorbed (18 to 20 lb. per cubic foot of wood) was excessive for the class of material involved, and heavy bleeding resulted; based on an average volume of 1.88 cu. ft. per pole and a creosote cost of 21 cts. per gallon, the preservative cost alone amounted to approximately 86 cts. per pole. The absorption could be reduced by decreasing the length of time that the wood was held in either, or both, of the regular baths but only at a very marked sacrifice in depth of penetration. It was finally determined that the desired results could be obtained if, following a 1-hr. hot bath (220 to 225°F.), the poles were allowed to stand in the cold preservative (100°F.) only long enough to receive a penetration of about 1 in. (as indicated by borings) and then replaced in the hot bath for 30 min. Timbers treated in this way had an average penetration of 1.83 in. and an average absorption of 12.8 lb. of creosote per cubic foot, which was considered sufficient for protection and did not induce bleeding in the poles.

An adequate hot-and-cold-bath treatment with preservative oils is the best substitute for pressure impregnation. The process finds extensive commercial use in the butt treatment of poles, especially those of cedar and chestnut. More than 14 million poles were given such treatment during the decade ending in 1934. In the northern and western parts of the country, the above-ground parts of cedar and chestnut timbers are sufficiently durable to give long service in their natural condition, so that it is necessary to treat such poles only to a height of about 1 ft. above the ground line. On the other hand, round timbers that are apt to decay rather rapidly above ground, such as the southern pines, require full-length treatment in most sections of the country if the service life of the poles is to be materially increased. The hot-and-cold-bath process is also frequently used for the treatment of fence posts, lumber, and various other forms of timber, especially in small quantities; such material may be entirely immersed or treated over only part of its length, according to the requirements of service. The penetrations obtained with preservative oils are usually shallower and more erratic, and the absorptions less subject to control than in the pressure processes, but, when skillfully applied to wood that takes treatment at least reasonably well, the hot and cold bath gives a high degree of protection. The process can also be made to give very good results with salt solutions.

The U.S. Forest Service has used the hot-and-cold-bath process extensively for butt-treating posts, poles, and pole stubs, especially in the Rocky Mountain region. Both the lodgepole and ponderosa pines, which are plentiful throughout most of that region, can be effectively treated by this method. A portable open tank, designed for such work, is shown in Fig. 74; and a U.S. Forest Service plant in operation, in Fig. 75.

A patented variation of the hot-and-cold-bath process (U.S. pat. 1,991,811, issued to Frank H. Lyons, Feb. 19, 1935) provides for heating wood in a humidity-controlled kiln, instead of in hot liquid, and then submerging it in a bath of cool preservative, which is usually maintained at atmospheric temperature. This method may be used with both oils and water solutions but is especially suited for preservatives that cannot safely be heated in open tanks because of their high content of volatile organic solvents (page 123). By keeping the humidity of the kiln at the proper point during the heating process, the wood can be warmed satisfactorily without decreasing its moisture content, thus avoiding any danger of shrinking and checking the material. This is especially important with finished products, or the finished parts of unassembled products, such as window sash and frames, doors, millwork, flooring blocks, and furniture.

MISCELLANEOUS NONPRESSURE PROCESSES

Charring.—The process of charring the surfaces of wood over a fire or with a torch, in order to prevent decay, is so old that its origin is unknown. Its use was probably based on the observation that charcoal seems to resist decay indefinitely and the resultant belief that a layer of charcoal on the surface of a fence post or other timber would protect the wood beneath from attack by wood-destroying fungi. Owing to the fragility of the charcoal, however, it is practically impossible to maintain a continuous layer over the surface, and decay can usually reach untreated wood through checks or at places where the charcoal sheath has been broken away. Such experiments as have been made to determine the durability of charred posts have usually shown that little, if any, protection was afforded by the treatment, although favorable results have occasionally been reported.

Charring and Spraying.—Charring has been used in several processes, as a preparatory step to spraying standing poles with creosote. When used in this way, the treatment is intended to dry and sterilize the surface layers of the wood and to provide a thin shell of charcoal, which will absorb the creosote and thus serve as a preservative reservoir. The drying of the surface layers, as the result of the charring, may also result in the formation of numerous, small checks, and thus enable the preservative to reach the uncharred wood directly.

The *Furnos process* (8), developed in Sweden about 1920, consists in digging away the soil from the base of a pole to a depth of about 1½ to 2 ft., cleaning away all visibly decayed wood, allowing the exposed exterior to dry for a few days, charring the surface above and below the ground line with a broad-flame, kerosene blowtorch, and then immediately spraying the hot, charred area generously with creosote. The treated wood is then exposed to the air for a few days, before the hole is refilled with dirt. The process admittedly provides only a surface treatment, and is unable to stop decay that may be developing within the interior of a pole. However, the promoters contend that it will hold surface decay in check for at least 5 years in a pole that is sound at the heart, and that continued protection will be afforded if the treatment is renewed at approximately 5-year intervals.

In 1926, a patent (U.S. 1,574,662) was issued to Randolph Leedom, covering substantially the same details as the Furnos process, which had not been patented in the United States. During the next few years, this process (Fig. 55) was used on thousands of old untreated poles in the lines of the Western Union Telegraph Company. (9, 10.) Small poles and those that were unsound at the heart were not charred and sprayed, but it was felt that the treatment would extend the life of other timbers, that were beginning to decay at the ground line, more than enough to cover the cost. The procedure was not always effective, however, and in some cases the decay continued to develop progressively deeper into the wood. In certain poles the trouble could be traced to incomplete removal of infected wood during the cleaning operation or to careless treatment, while in others the fungi presumably entered the untreated interior through relatively deep surface checks or by direct growth from infected wood below the treated zone. Despite the occasional failures, however, the average increase in service life of treated poles was believed to be about 5 years. The cost of treatment varied widely; on some jobs it was reported to be as low as $0.50, while on others it amounted to $1.50 or more per pole. The use of this process was discontinued after a few years, apparently because most of the old poles had been treated. There is also some question as to the relative economy of continuing old poles in service or of replacing them with new ones.

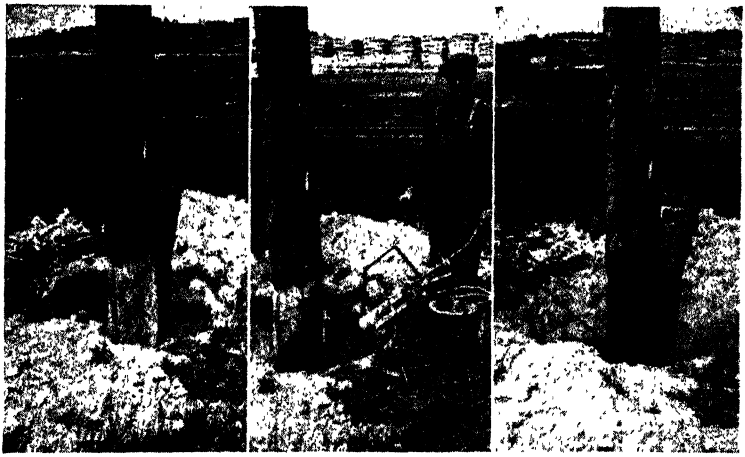

FIG. 55.—Three steps in the charring and spraying treatment formerly used by the Western Union Telegraph Co. for extending the life of partially decayed standing poles. Left, pole excavated, and decayed portions removed; center, charring with a blowtorch; right, creosote sprayed over charred surface.

The *Oxyacetylene process*, now being promoted in Australia, is essentially the same as the Furnos method. Its promoters claim, however, that the oxyacetylene flame provided by their special burners gives superior results in charring infected wood and in sterilizing the pole surface. The process is being investigated by the Forest Products Division of the Australian Council for Scientific and Industrial Research (5), but no decision has yet been reached as to how much reliance can be placed upon the treatment.

Diffusion Processes.—There are a number of methods of treating timber (in addition to the steeping process) in which penetration is dependent upon the gradual diffusion of preservative into the wood from a concentrated source of supply. In practically all of the processes of this type that have been developed in recent years, the preservative is applied to the surface of the wood. But attempts have also been made, from very early times, to perfect a method for impregnating wood by introducing the toxic chemical through holes bored for some distance into the interior of timbers.

The *Anaconda (dry) process* was developed by the Anaconda Copper Mining Company (U.S. pat. 1,639,601, issued to H. C. Gardiner, Aug. 16, 1927) and used for a number of years for treating poles and posts with a dry form of crude arsenic (arsenic trioxide) known as *Anaconda wood preservative*, or *treater dust* (page 127). In treating a new pole, a quantity of the preservative, in powder or granule form, was first placed in the bottom of a freshly excavated hole. Then, after erecting the pole and backfilling the hole to about one-third of its depth, added preservative was poured around the timber to form a ring in close contact with the wood. The hole was then filled with dirt to about 12 to 18 in. from the top, and another ring of crude arsenic added, after which the backfilling was completed. The total quantity of preservative used, as well as the precise placement of the rings, varied somewhat with the size of the pole and with the opinions of those employing the process. It was common practice, however, to use about 10 lb. for a pole 12 in. in diameter. Fence posts were treated with only one ring, instead of two, and 1½ lb. of preservative were considered sufficient, on the average.

When the crude arsenic takes up water from the ground, it forms a pasty mass which is capable of remaining in that condition for years and thus acting as a reservoir of preservative. The soil moisture tends to spread some of the preservative over the entire underground surface of the pole as well as to carry it for some distance above the ground line, and penetration is obtained by the gradual diffusion of arsenic solution into the wood. Difficulties were encountered in relatively dry soils, in which the amount of available moisture, while adequate for the development of decay-producing fungi, was not sufficient to carry the preservative quickly over the surface of the wood.

In such cases, decay or termites were able to invade the timber between the rings of preservative. Even in more moist soils, however, the treatment was not always effective. As a result, the use of the dry crude arsenic was discontinued, and a method of applying the preservative in paste form was developed.

The *Anaconda (paste) process* (U.S. pat. 1,859,203, issued to H. C. Gardiner, May 17, 1932) provides for the application of a coating of Anaconda wood-preservative paste (page 127) over part or all of the underground surface of a pole or post. In making the paste, the crude arsenic (*smelter dust*) is compounded with enough water to give it the desired consistency and with a hygroscopic substance that will continue to attract moisture from the soil and thus prevent the preservative from drying out. The paste is considered more effective than the powder, since it affords an immediate supply of moisture and thus causes the preservative to begin penetrating the wood at once. The original paste method, used in treating new poles, provided for coating the bottom end of a timber as well as applying a wide band of the paste completely around the circumference for a distance of about 2 ft. downward, beginning at a point 6 in. below the ground line. Experience showed that the preservative did not spread upward with sufficient rapidity to prevent decay between the ground line and the top of the band of paste. In subsequent treatments, therefore, the paste band was extended up to the ground line.

A later variation of this method, employed in the treatment of new poles in the Pacific Northwest, consists in applying a layer of paste, about ⅛ in. thick, to the bottom of the timber and over the butt surface, from the ground line to a point 18 in. below. Such a treatment requires about 3½ to 6 lb. of paste per pole, depending on the size of the timber. The 18-in. band of preservative is then wrapped with burlap, after which the pole is set in the hole so that the upper edge of the band is at the ground line. After the hole has been partially backfilled, a strip of tough waterproof paper, 9 in. in width, is tacked around the pole, extending from about 3 in. above to about 6 in. below the ground. This is intended to protect animals from possible contact with the preservative. As a further protection, a ring of barbed wire is tacked around the pole, about 2 in. above the ground line, before the backfilling is completed. Because of the poisonous nature of the crude arsenic, great care should be taken to bury all empty containers and to leave no scraps of paste on the ground.

In treating new fence posts with the paste, it is considered good practice to coat the entire underground surface, using 2 or 3 lb. of preservative per post.

The treatment of standing poles that have already begun to decay is, in general, similar to that of new poles. Both the dry and the paste forms of Anaconda wood preservative have been used in the past, but only the paste is now recommended. The soil is dug away from a pole to a depth of 18 to 24 in., and the decayed wood is removed as completely as possible. Paste is then applied to all the pole surface exposed below the ground line, after which the soil is backfilled. As a protection against removing any of the paste from the wood during backfilling as well as against animals getting at the preservative, the treated surface may be wrapped with heavy building paper before the soil is shoveled back into the hole.

The degree of protection that the paste treatment may afford to either new poles (or posts) or those already in service has not yet been determined. The earlier applications, which were neither extended up to the ground line nor wrapped with paper, often failed to give satisfactory protection. On the other hand, poles treated after these improvements were adopted have not been in service long enough to indicate the results that may be expected. However, thousands of poles have been so treated in the Pacific Northwest in the past few years, and these should soon begin to supply valuable information.

The *Osmose process,* developed in Germany and used commercially since about 1933, is covered by British patent 381,030, issued to Carl Schmittutz on Sept. 29, 1932, and by United States patents 2,012,975 and 2,012,976, issued to Schmittutz on Sept. 3, 1935. It makes use of a fluoride-phenol type of preservative, generally similar to Wolman salts but applied to the wood in paste form. A glutinous colloid is included in the mixture, so that the sodium fluoride, dinitrophenol, and bichromate will form a thin paste when mixed with water. When protection is desired against termites, as well as decay, sodium arsenate is included. The preservative is applied with a brush, and the amount of paste used will depend largely upon the surface area to be covered. For the complete (over-all) treatment of products such as poles and crossties, ¼ lb. of dry compound per cubic foot of wood is recommended.

The Osmose process is designed for the treatment of green or moisture-laden wood only. Hence, when poles, posts, ties, or other products are to be treated before installation, the preservative should be applied as soon as possible after the timber is cut and peeled. The paste is brushed over all surfaces to be treated, and the timbers are then stacked in solid piles and completely covered with waterproof crepe paper or other suitable material, which will retard the loss of moisture from the wood and also protect the paste from being washed off by rain. After a period of 14 to 90 days, depending on the size of the timbers, the process is considered to be practically complete, and the piles are uncovered. The pieces should be air seasoned for at least 30 days before being placed in service, the rate of drying being so regulated as to prevent the development of deep checks which would expose the untreated interior of the timbers to direct attack by decay (or termites).

The process is also used for the ground-line treatment of standing poles and land piles. The soil is dug away from such timbers to a depth of from 1½ to 2 ft., and increment borings are taken over the exposed area to determine the soundness of the interior wood and the thickness of the undecayed shell of timber. If the condition of the pole or pile is such as to justify treatment, the decayed surface wood is removed as thoroughly as possible, and the preservative brushed over an area extending from 18 in. below to 6 in. above the ground line. The band of paste is then wrapped spirally with waterproof jute bandage or heavy coated paper, after which the hole is backfilled. The cost of treatment, including preservative, labor, and other charges, is said to be about $2 to $3 per pole.

The Osmose process depends entirely upon diffusion to carry the preservative from the paste into the wood, so that the higher the moisture content of the timber, the better the penetration will be. Under favorable conditions, deep penetrations can be obtained in the sapwood, and even the heartwood may be treated to considerable depth. It is claimed, in Germany, that better penetrations have been obtained in treating spruce and fir by the Osmose process than by any other method, including the pressure treatments. The process is still very new in the United States, where it has been applied mainly to standing poles. Consequently, adequate data have not yet been obtained to indicate either the penetration to be expected in heartwood and sapwood of different species or the extent to which the service life of various timbers may be increased. It is claimed, however, that the Osmose treatment of standing poles will add about 7 years to their life.

Preservative bandages have also been used to some extent for treating wood by diffusion. They appear to have been employed experimentally in Sweden as early as 1920 (16) and, under the name of the *Ahig process*, were actively promoted in Germany in 1928. In treating poles by this method, a broad bandage of quilted cloth or other suitable material impregnated or coated with a salt preservative was wrapped tightly around the timber over the ground-line area. The natural moisture in the soil and timber caused the salt to diffuse into the wood. Other bandages were devised for treating the top ends of poles, as well as the contact points in the "A" and other compound poles so extensively used in Europe. United States patent 1,981,664, issued Nov. 20, 1934, to D. A. Quarles, covers essentially the same process as the foregoing.

As originally patented, the Osmose process involved the application of preservative bandages to unseasoned poles before installation. A long strip of heavy paper, coated on the inside with preservative, was wrapped spirally around the pole over the area to be treated. Essentially, there is no great difference between this method and the present Osmose process for treating standing poles, in which the preservative paste is brushed directly on the pole and subsequently covered with a protective wrapping. The latter procedure, however, gives greater certainty of completely coating the surface to be treated, better contact between the preservative and the wood, and probably better penetration of the toxic chemicals.

There has been little, if any, commercial application of bandage processes in the United States. While they appear to have found some use in Germany and have been experimented with in Sweden and Australia, their practicability and effectiveness have not yet been established. In general, they do not seem to be very promising.

Preservatives in Bored Holes.—A very old method of treating poles, posts, and other timbers in place, is to bore holes in the wood at the ground line or other point of severe fungus attack, fill them with a preservative (liquid, powder, or paste), and then plug them with suitable stoppers. The preservative is expected to diffuse gradually throughout the danger zone and thus protect the timber from decay.

In one variation of the method, tried by a public utility company on the Pacific coast for treating Douglas fir poles (1), four 1-in. holes were bored in a pole near the ground line, slanting downward and toward the vertical axis of the timber. These openings were filled with a preservative mixture containing one part mercuric chloride, one part arsenic, and four parts common salt, after which the holes were plugged with corks. The common salt was added to attract moisture and thus hasten the diffusion of the preservative throughout the wood. The treatment was also restricted to green poles, in order further to facilitate diffusion. The wood immediately above and below the holes was usually well treated, but the rest of the ground-line section was often not penetrated sufficiently to afford any definite protection to the timber. Another utility company in the same region treated several thousand Douglas fir poles by a similar process but found so much decay after about one to two years of service that all the poles were re-treated by another method. The process affords uncertain decay protection, and, in addition, the boring of so many holes near the ground line has a decided weakening effect on the timber.

The simplicity of this general method of treatment makes it very attractive, and in some cases it apparently has given rather promising results. However, the process has not proved generally reliable and has never found extensive use.

Setting Timber in Stones or Concrete.—It is occasionally claimed that decay will be materially retarded in poles or posts if the holes in which such timbers are installed are filled with stones rather than soil. There is little evidence to support such claims, however, and no apparent reason why the practice should be effective. Since the stones do not make close contact with the entire surface of the wood, they are presumed to provide better opportunity for ventilation around the pole base, thus tending to keep the wood relatively dry and making conditions less favorable for decay. Such drying will not be effective to any marked depth below the ground level, however, so that the only probable result of this practice would be to lower the zone of greatest decay. Provided dirt and debris do not fill the interstices between the stones, timbers set in this manner may be expected to show maximum deterioration farther below the surface of the ground than those in soil-filled holes.

Poles have probably been set in concrete more frequently than in stones. A definite advantage of this method of installation, especially in soft ground, is that it adds to the stability of the timber by increasing the effective bearing area. As a means of retarding decay, however, the practice has nothing to recommend it. The concrete is not moisture proof, and, furthermore, cracks usually develop in it and between it and the wood. Such openings, together with the checks that normally occur in wood, admit plenty of moisture to the timber at and below the ground line and make conditions just about as favorable for decay as if the wood were in direct contact with the soil.

Arsenic Concrete.—A somewhat different type of concrete treatment for poles is covered by a Swedish patent (No. 80,642, issued Feb. 7, 1931, to A. G. P. Palen), which provides for the addition of arsenic to the cement mixture. The poles may be either set in a mass of this arsenic concrete or merely coated with the material. It is claimed that the arsenic diffuses into the wood from the concrete. Records on the effectiveness of the treatment are not available.

Treating Standing Trees.—Since the idea was first advanced, early in the nineteenth century, innumerable attempts have been made to devise practical methods for injecting preservatives (or dyes) into living trees. The original Boucherie treatment was of this kind, the process now known under that name being a later development. The numerous processes that have since been advocated vary widely as to the chemical solutions used and the methods of application, but all of them are based upon the principle that solutions entering the sapwood of living trees are carried in the sap stream for long distances. The travel is essentially vertical, being especially extensive upward from the point of entrance; and for this reason, as well as for greater convenience, the chemicals are usually introduced near the base of a tree. Since the horizontal spread is generally slight, the aim should be to cut deeply into the wood around the entire circumference of the trunk but in such a way that the tree cannot sway in the wind to the extent that it is in danger of falling. Severance of most of the sapwood seems to be required for complete sapwood treatment, but, since penetration into the heartwood is not significant, no advantage is gained by cutting into that part of the tree. Best results in the distribution of chemicals are obtained during periods of active transpiration from the leaves (2). The chemicals, which are sometimes carried into the leaves and even the seeds as well as into the roots, usually cause the tree to die.

This general procedure of introducing chemicals into living trees seems to have been advocated for coloring wood more often than for injecting toxic substances, but it is frequently suggested as a wood-preserving method. It has also been studied by the U.S. Bureau of Entomology and Plant Quarantine and appears to have considerable merit as a means of controlling epidemics of insects that attack living trees and invade the wood to greater or lesser degree. When successfully applied, such a treatment will cause the death of the insects. The trees killed by the treatment would probably die anyway as the result of the insect attack. Standing dead trees, containing substantial amounts of preservative injected in this manner, have been found to remain free from decay and insect attack and to retain their bark for some years.

One treatment for standing trees, patented by Levi S. Gardner (U.S. pat. 952,245, Mar. 15, 1910), provides for cutting a deep saw kerf around the base of a tree, closing the outer edge of the cut with a suitable packing or gasket, and then admitting a dye solution into the chamber thus formed. The solution is placed in a pail hung on the tree and siphoned, by means of a hose and plug, through the gasket into the interior of the saw kerf. Although Gardner included only dyeing solutions in his patent, his method is equally suitable for preservative solutions.

In another method, patented by H. Renner (U.S. pat. 1,727,939, Sept. 10, 1929), a horizontal hole is bored completely through the tree trunk near the base. A small two-edged saw is then inserted, and two opposite quadrants of the cross section are sawed through. A second hole is bored through the tree, a foot or so above or below the first one and at right angles to it, and the other two quadrants are sawed through. This leaves the trunk severed, but in such a way that the tree does not fall. The two series of openings are then connected by bored holes, which are closed at their outer ends, and all exposed edges are covered with packing or other suitable material, thus forming a chamber into which the dye or preservative can be fed by gravity.

Carl Schmittutz (U.S. pat. 1,973,394, Sept. 11, 1934) describes a method of treating standing timber, which involves peeling the bark entirely around a tree near the ground line, brushing a preservative paste over the exposed wood surface, and then covering the treatment with a protective coating of waterproof paper. In this method, the lateral movement of the preservative into the sapwood takes place at the base of the tree, as the result of the diffusion of the chemical from the paste; the toxicant is then distributed vertically in the sap stream from this penetrated basal zone. The amount of preservative that can be injected into standing trees in this way, and the depth and uniformity of penetration obtained, remain to be determined.

In the experiments with standing trees, carried on by the U.S. Bureau of Entomology and Plant Quarantine, it has been found possible to obtain complete sapwood penetration in southern pine, by cutting a spiral saw kerf or groove around a tree to a depth of about 1 in., covering the groove with a tightly stretched rubber band, and leading preservative solution through a tube into the space thus formed. The required quantity of solution is placed in a container hung on the tree from a few inches to a foot above the rubber band and is siphoned into the inlet tube of the groove (Fig. 56). Trees up to 8 in. in diameter take up the solution in from 4 to 12 hr.; a longer period is presumably required for larger trees, because of the greater amount of solution injected. It is advisable to allow a week for the preservative to distribute itself evenly throughout the sapwood of the tree.

Another method used in the foregoing experiments involves felling a tree and treating it before removing the branches. A chamber is formed over the cut end of the tree by removing the bark for a distance of 1 ft., slipping one end of the inner tube of a truck tire over this area, and binding it in place with a wire. The other end of the tube is fastened to a support somewhat higher than the end of the tree, and preservative solution is then poured into the tube (Fig. 56). The transpiration of moisture from the leaves causes the preservative to be drawn into the sapwood.

Still another method, used with trees small enough to be lifted, consists of cutting a tree from the stump and leaning it against another tree or other suitable support; the cut end is then placed in a container of preservative solution (Fig. 56). Ordinarily, the solution will be absorbed within a day, but complete distribution in the sapwood will not be obtained for about 7 days.

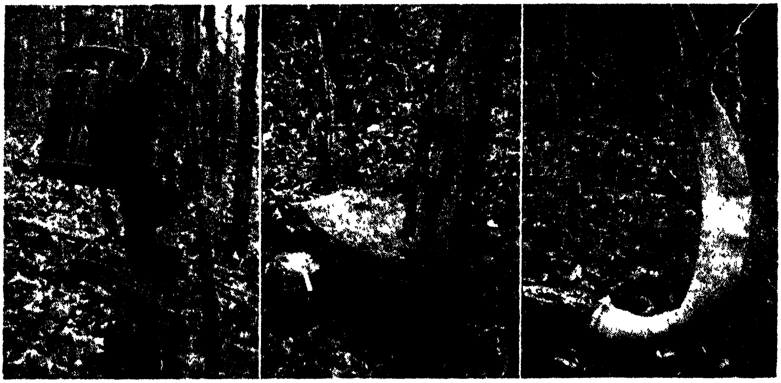

Fig. 56.—Three adaptations of the Boucherie method of treating trees, developed by the U.S. Bureau of Entomology and Plant Quarantine. Left, banding method: preservative siphoned into a spiral saw kerf in the standing tree; center, stepping method: freshly cut, untrimmed tree stood in a container of preservative; right, capping method: piece of tire inner tube fastened over the end of a freshly felled, untrimmed tree serves as a preservative container. (*U.S. Bureau of Entomology and Plant Quarantine.*)

Despite the many methods proposed for impregnating living trees with preservatives or dyes, no process of this type seems to have achieved commercial success. On the whole, the application of preservatives to individual trees in the forest is not so advantageous as treating timber by pressure methods after it has been fashioned for service. However, the living-tree treatments may occasionally be used to advantage in regions remote from treating plants or for the treatment of wood for rustic structures, especially if the bark is to be retained. The benefits resulting from such treatments will be increased as suitable water-borne preservatives, high in both effectiveness and resistance to leaching, are developed.

Pitch Treatment of Standing Trees.—United States patent 655,638, issued to J. G. Robinson on Aug. 7, 1900, covers a method of partially removing the bark from standing pine trees, so as to encourage the accumulation of pitch or resin in and upon the exposed wood. It may be considered, therefore, as a process of forming and diffusing a natural preservative into wood. Although pine wood containing a high percentage of resin is known to be very resistant to decay and termites, it is improbable that this method will give reliable results, since the peeled areas are likely to be merely coated with the resin rather than impregnated with it. Furthermore, a sizable strip of bark must be left intact through the length of the peeled area, if the early death of the tree is to be avoided. Lodgepole pine treated in this manner failed to give good service in Montana (19).

PRESSURE PROCESSES

The most successful and widely used of the pressure processes are those in which the treatment is carried on in closed cylinders. In general, such processes have a number of definite advantages over the nonpressure methods. Outstanding is the fact that, in most cases, a deeper and more uniform penetration and a higher absorption of preservative can be secured, thus providing more effective protection to the timber. Furthermore, the treating conditions may usually be so controlled that absorption and penetration can be varied to meet the requirements of service, thus resulting in more economical use of preservative. Special manipulations, or preliminary treatments, within the cylinder also make it possible to impregnate unseasoned wood or to sterilize the timber. Finally, these pressure processes are adapted to the large-scale production of treated material. Among the disadvantages that may be cited are the amount and expense of the equipment required, the cost of the labor involved, and the frequent necessity of shipping the timber for long distances to and from the treating plant, all of which result in a decided increase in cost of treatment over that usually involved in the nonpressure processes. The pressure methods also entail the complete (over-all) treatment of the timber and, as commonly used, are not applicable to localized injections of preservative.

While the various pressure processes differ in details, the general method of handling the material is the same in all cases.

The treatment is carried on in cylinders or retorts, mostly within the limits of 6 to 9 ft. in diameter and up to 150 ft. or more in length, and built to withstand working pressures up to 250 lb. per square inch. The ties, poles, structural timbers, or other forms of timber are loaded on special tram cars, or "buggies," which are moved about the treating yard and in and out of the cylinder on steel tracks. Storage and measuring tanks, pressure and vacuum pumps, steam boilers, and other plant equipment must also be provided.*

The various pressure methods used for injecting preservatives into wood in closed cylinders may be divided into two main groups, designated as *full-cell* and *empty-cell* processes. In the full-cell process, the aim is to retain as much of the liquid forced into the wood during the pressure period as possible, thus leaving the maximum concentration of preservative in the treated zone. In the empty-cell processes, on the other hand, part of the preservative forced into the timber under pressure is subsequently recovered, so that the cells tend to be coated with preservative rather than filled with it. Neither process leaves the cells full or empty, but the names full cell and empty cell are sufficiently accurate for practical purposes.

The full-cell process is especially advantageous when it is desired to inject as much preservative solution as the wood can take. Empty-cell methods are required when it is desired to secure as deep penetration as possible with a limited final retention of liquid. When wood is to be treated with preservative oils, the empty-cell processes will generally give best results. Exceptions are noted in the case of marine piling, in which the absorption (net retention) should be as great as possible, and in certain other instances in which the specified or desired amount of oil cannot be injected except by the full-cell method. When less than the maximum obtainable absorption is required, deeper and more uniform penetration will be obtained by the empty-cell treatments.

When treating with water solutions of preservative salts, it is customary to use the full-cell process and to force into the wood all of the liquid that it can hold. The desired absorption (amount of dry salt per cubic foot of wood) is obtained by regulating the strength of the solution rather than by limiting the amount of liquid injected into the timber. Empty-cell methods may be used with aqueous solutions, however, when it is desired either to follow a salt treatment with an immediate injection of oil or to minimize the increase in weight of wood that must be shipped soon after treatment.

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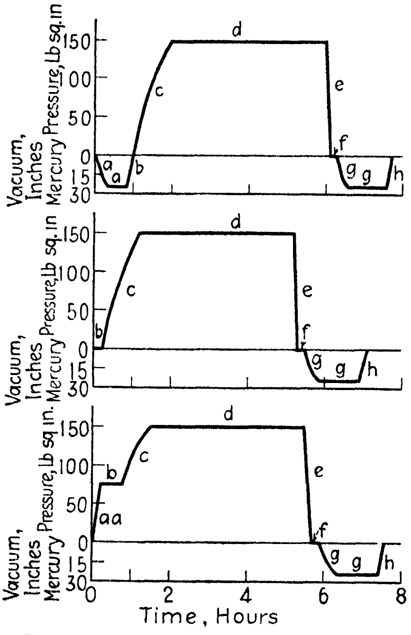
* Plant equipment is discussed in Chap. X.

FULL-CELL PROCESS

A considerable number of treatments, following the general procedure of the full-cell process, were devised and patented during the past century, but only the Bethell and Burnett methods are extensively used today in this country. The former is employed for impregnating wood with creosote and other preservative oils, while the latter is the standard method for zinc chloride and other water-borne preservatives. The Wolman, Zinc-meta-arsenite, Celcure, and Chemonite treatments are of the Burnett type, differing from it primarily in the kind of preservative used. Brief mention is also made of the Allardyce, Card, Creoaire, Rütgers, and Wellhouse treatments, which are no longer in use but are of interest from the historical point of view.

BETHELL PROCESS

This process was patented by John Bethell (Brit. pat. 7731, July 11, 1838) and covered, among other features, the injection of tar and "dead oil of tar" into wood by applying pressure in closed cylinders. As practiced today, the general procedure outlined in the original patent is still followed, although there have been marked improvements in the mechanical phases of the treatment. Seasoned wood is placed in the treating cylinder; the cylinder doors are sealed; and a preliminary vacuum is drawn on the charge. This vacuum, which is usually carried to a maximum of at least 22 in., is maintained for from 15 min. to an hour. Then, without admitting air, the cylinder is completely filled with hot preservative oil, after which additional oil is forced into the retort to build up the required pressure. The pressure generally reaches a maximum of from 125 to 200 lb. per square inch and is maintained until the desired absorption is attained, or to virtual refusal. The temperature of the preservative is usually required to average at least 180°F. and not to exceed 210°F. When the required amount of preservative has been injected into the wood, the pressure is released, and the oil drained from the cylinder. A short final vacuum is usually applied to dry the surface of the timber, although this step was not provided for in the original Bethell patent. The various steps in the full-cell process are diagrammed in Fig. 57. The distinguishing characteristic of this, and also every other, full-cell treatment is the preliminary vacuum, the purpose of which is to exhaust part of the air from the outer layers of the wood. This not only facilitates the entrance of preservative into the wood but also largely eliminates any cushioning effect of the air, which would otherwise force out part of the injected preservative when pressure is released.



FULL-CELL PROCESS
a. Preliminary vacuum period
b. Filling cylinder with preservative
c. Pressure rising to maximum
d. Maximum pressure maintained
e. Pressure released
f. Preservative withdrawn
g. Final vacuum period
h. Vacuum released

LOWRY PROCESS
b. Filling cylinder with preservative at atmospheric pressure
c. to *h.*—Pressure period and final vacuum, as in full-cell treatment

RUEPING PROCESS
aa. Preliminary air pressure applied
b. Filling cylinder, while pressure maintained
c. to *h.* Pressure period and final vacuum, as in full-cell treatment.

FIG. 57.—Typical pressure diagrams for full-cell, Lowry, and Rueping processes. When green wood is treated, a preliminary conditioning process precedes the steps shown in the diagrams. The duration of the different steps as well as the intensity of vacuum, pressure, and preservative temperature varies widely according to the character and condition of the wood and the judgment of the plant operator or timber purchaser.

Some operators attach great importance to the intensity and duration of the preliminary vacuum, and take pains to obtain as high a vacuum as practicable and to hold it for more than 30 min. They also keep the vacuum pump running while the cylinder is being filled with preservative, in order to remove any air that may be forced out of the wood when it is first contacted by the hot oil. There can be no question that these special precautions tend to reduce the amount of air remaining in the wood, and they may prove important in special treatments, where the highest possible absorption is required. It is very doubtful, however, that they have much significance in commercial treatments.

BURNETT PROCESS

In 1838, William Burnett of England obtained a patent (Brit. pat. 7747) covering the use of zinc chloride as a wood preservative, and since that time the treatment of wood with this salt has been known as Burnettizing, or the Burnett process. The original patent provided for steeping the wood for 10 to 21 days in a 2.4 per cent solution of zinc chloride, and the injection of a solution under pressure in closed cylinders was a later development, being first undertaken in 1847.

As practiced today, the Burnett process embodies the same general procedure as the Bethell process. The preliminary vacuum is followed by the admission of the preservative solution and the application of pressure, which may amount to as much as 200 lb. per square inch. The solution temperatures may range from atmospheric to 210°F. but generally average at least 150°F. This is a low average temperature for best results and should be raised to at least 190°F. when treating resistant wood. When virtually no more preservative can be forced into the timber (treatment to approximate refusal), the pressure is released, and the cylinder drained. A short final vacuum is usually called for in treating specifications. The strength of the treating solution generally varies from 2 to 4 per cent, depending upon the amount of liquid that can be forced into the timber; it is so regulated as to give an absorption of from ½ to 1¼ lb. of *dry* zinc chloride per cubic foot of wood.

MISCELLANEOUS FULL-CELL TREATMENTS

Celcure Treatment.—This term, as commonly used, relates to the preservative employed (page 129) rather than to the process of applying it, for both pressure and nonpressure methods are advocated by its promoters. In the impregnation of wood with

Celcure preservative, however, a regular full-cell treatment should be employed. In this case, the only variation from the normal procedure occurs when it is desired to hasten the reaction that is claimed to take place between the ingredients of the preservative after their injection into the wood. In such a case, the timber is steamed following the pressure period.

Chemonite Treatment.—This is a regular full-cell treatment, using the Chemonite preservative (page 129). In order to avoid loss of ammonia from the solution, the preservative should be used at ordinary atmospheric temperatures and kept in closed containers as much as possible.

Wolman Treatment.—The impregnation of wood with Wolman salts (page 131) is sometimes referred to as the Wolman process. The procedure employed does not differ essentially from that of the ordinary full-cell treatment, except that the temperature of the preservative solution is usually kept below 150°F. However, the promoters of these preservatives seem to consider a high preliminary vacuum as especially important. In Wolmanizing wood, a final air pressure may sometimes be applied, after the preservative has been injected and the cylinder drained. The purpose of this added step in the treatment is to force the preservative deeper into the wood.

Zinc-meta-arsenite (Z.M.A.) Treatment.—In this treatment, zinc-meta-arsenite (page 132) is used as the preservative. The method of impregnating does not differ from the ordinary full-cell treatment, except that the Z.M.A. solution is not heated much above atmospheric temperature. Zinc-meta-arsenite is sometimes used in a two-movement treatment with petroleum oil, in which case the first impregnation (with the Z.M.A. solution) may be made by an empty-cell process.

Full-cell Treatments Not Now in Use.—There are a number of additional full-cell methods of impregnating timber, which, while not used commercially at the present time, are occasionally referred to in the literature, especially in connection with service records on railway ties and piles. The most important of these are discussed briefly in the following paragraphs.

The *Allardyce treatment* was devised by R. L. Allardyce and used to some extent in the United States late in the last century and in the early 1900's but was never patented. It was a two-movement treatment, the first impregnation being made with a

2 to 3 per cent solution of zinc chloride, which was forced into the wood under a pressure of about 75 to 100 lb. per square inch until the desired absorption (generally from ¼ to ½ lb. of dry salt per cubic foot) was secured. Following this, creosote was injected into the timber under a pressure of from 100 to 150 lb., until an absorption of about 3 lb. per cubic foot was attained.

A somewhat similar treatment was patented in 1885 by J. P. Card (U.S. pat. 317,440), but in this the order of impregnation was reversed, the zinc chloride solution being injected after a limited amount of creosote had been forced into the wood. Two-movement treatments, such as these, are naturally more expensive and probably no more effective than methods, like the Card treatment of 1906, in which the same two preservatives are mixed beforehand and injected in a single step.

The *Card treatment*, patented in 1906 by J. B. Card (U.S. pat. 815,404), provided for the use of a preservative consisting of a mixture of approximately 80 per cent of a zinc chloride solution and 20 per cent coal-tar creosote. The strength of the salt solution (2½ to 5 per cent) and the actual proportion of creosote in the mixture were varied according to the kind of timber to be treated and were usually such as to result in an absorption of about ½ lb. of *dry* zinc chloride and 2 or 3 lb. of oil per cubic foot of wood. The two ingredients would normally separate in the treating cylinder during the pressure period, with the result that the upper part of the charge would receive a surplus of one constituent, and the lower part an excess of the other. A high-gravity creosote would sink to the bottom of the cylinder, while a low-gravity oil would rise to the top. Violent agitation of the preservative was necessary, therefore, to keep the creosote and zinc chloride thoroughly mixed during treatment. This was accomplished by a powerful pump which drew the mixture from one part of the retort and returned it to another, thus maintaining a rapid circulation of the liquid. Both ingredients entered the wood, but the zinc chloride solution penetrated farther than the creosote. The Card treatment was a full-cell process and, aside from the preservative used and the necessity for keeping it agitated, was carried out in essentially the same manner as the Bethell process.

Experience has shown (13) that railway ties treated by the Card preservative have a somewhat longer service life than those impregnated with straight zinc chloride (½ lb. per cubic foot) but are not so lasting as ties treated with straight coal-tar creosote. Although formerly employed quite extensively in the treatment of ties, the Card process is no longer used.

The *Creoaire treatment*, used by a creosoting company in the South about 1905, involved the application of air pressure to treated wood, after the surplus preservative had been drained from the cylinder. It was claimed that the high final air pressure had the effect of increasing the depth of penetration. The method did not prove so effective as claimed and was not extensively used, although a final air pressure has been employed, with variations, from time to time at different plants.

The *Rütgers treatment*, an unpatented forerunner of the Card method of 1906, was advocated by Julius Rütgers in Germany in the early 1870's and used in that country to some extent until 1920. It provided for the use of a preservative consisting of a mixture of zinc chloride solution and coal-tar creosote of high tar-acid content. The strength of the salt solution was approximately 2½ per cent, and the creosote used was of as nearly the same specific gravity (1.0244) as practicable, in order to minimize the tendency of the two substances to separate. The mixture was stirred with steam just before use, to emulsify it, but the emulsion was not stable, and the ingredients soon separated on standing. The German practice was to steam the wood first and then apply the emulsion under full-cell conditions (3).

In the *Wellhouse method*, patented in 1879 by William Wellhouse and Erwin Hagen (U.S. pat. 216,589), the wood was impregnated first with a solution containing both zinc chloride and gelatin (or glue) and then with a tannin solution. It was claimed that the tannin reacted with the gelatin (or glue) to produce a "leathery substance," which closed the pores of the wood and, being unaffected by moisture, prevented the leaching of the zinc chloride. It is very doubtful, however, that this treatment had any significant effect in reducing the leaching of the preservative salt.

By about 1900, the original method had been varied somewhat, and the process was being carried out as a three-movement treatment (4). The wood was first conditioned by steaming and vacuum, following which a zinc chloride solution of approximately 3.9 per cent strength was injected at a pressure of 100 lb.

per square inch and a temperature of 150°F., for about 3 hr. This impregnation was intended to give an absorption of ½ lb. of dry zinc chloride per cubic foot of wood. The preservative was then drained from the cylinder, and a gelatin solution was injected into the wood at a pressure of 100 lb. per square inch for about ½ to 1 hr. The cylinder was again drained, and a solution of tannin applied to the wood in a manner similar to that used with the gelatin. The time required for the entire treatment was about 12 hr.

The Wellhouse treatment was employed rather extensively during the latter part of the nineteenth century but was apparently little used after 1903. Any advantage that this method may have had over the straight Burnettizing process was apparently not sufficient to justify the extra expense, time, and inconvenience involved.

EMPTY-CELL PROCESSES

There are two distinct empty-cell methods, the Rueping and the Lowry, both of which are usually restricted to the treatment of timber with creosote or similar preservative oils, although either may be used for injecting water solutions. Both processes find wide application in the impregnation of such products as railway ties, poles, posts, lumber, and many forms of construction timbers, in which it is desired to obtain good penetrations with limited absorptions of preservative. They are specified by the American Wood-Preservers' Association, in preference to full-cell methods, for impregnating wood with oils in all cases where the absorption required is not greater than can be obtained by empty-cell methods.

Rueping Process

The Rueping (or Rüping) process was patented in this country in 1902 by Max Rüping of Germany (U.S. pat. 709,799). Its chief characteristic is the application of preliminary air pressure to the wood, prior to the injection of the preservative oil. The timber to be treated should be air dry for best results, but green material may be used, provided it is first conditioned by the steaming-and-vacuum or the boiling-under-vacuum method. Air is injected into the treating cylinder until the desired pressure is obtained, with the result that a certain amount is forced into the wood. The cylinder is then filled with preservative in such a way that the injected air is trapped in the wood. The filling may be accomplished by forcing the preservative into the bottom of the retort and allowing air to escape from the top just rapidly enough to maintain a constant pressure. Another way of carrying out the operation is to have the preservative in an overhead tank under the same pressure as the compressed air in the cylinder and, by means of a suitable arrangement of pipes, to allow the oil to flow into the retort by gravity while the air passes up into the space vacated by the preservative. After the filling is completed, the preservative is forced into the timber by the application of a higher pressure until the desired absorption is obtained, thus further compressing the air imprisoned in the wood. The pressure is then released, the preservative drained from the cylinder, and the charge subjected to a high final vacuum for a period of 30 min. or more. As soon as the pressure is released, the compressed air in the wood expands and forces out a considerable amount of the preservative that was injected. The final vacuum hastens the recovery* of oil and also shortens the period during which the preservative will continue to drip from the timber. As the result of this recovery, the net retention of preservative associated with a given penetration is definitely less than would be required to saturate the wood with oil to the same depth. It follows that, with a limited net retention, deeper penetration is obtained by the Rueping process than by the full-cell (Bethell) treatment. Figure 57 shows the several steps in the Rueping process.

The intensity of the preliminary air pressure is governed by the character of the wood being treated and the net absorption of preservative desired. When low absorptions are specified in wood that is very receptive to treatment, such as the air-dry sapwood of southern pine, air pressures as high as 100 lb. per square inch may be used. When more refractory woods or higher net retentions are involved, lower pressures are employed; in any given case, the precise intensity will depend largely upon the judgment of the operator, but pressures of 50 to 75 lb. per square inch are most common. In some plants, the practice is to start filling the cylinder with preservative as soon as the air pressure is built up to the desired amount; while in others, the maximum pressure is maintained for 15 to 30 min. before filling. The advantage of holding the pressure on the wood for such a period has not been established and is probably slight, at best.

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* The maximum amount of preservative contained in the wood at the end of the pressure period is called the *gross absorption;* the amount expelled after the release of the pressure but without the application of vacuum is termed the *kickback;* the amount recovered from the wood during the final vacuum is sometimes called the *drip* or *drain;* the kickback plus the drip constitute the total *recovery;* and the net amount left in the wood is known as the *net absorption,* or *net retention.* In commercial practice, kickback and drain are not determined separately.

The pressures employed in injecting preservatives into the wood are commonly about 100 lb. higher than the preliminary air pressures, but it is frequently inadvisable to increase them to such an extent. The preservative pressures seldom exceed 200 lb. per square inch, the maximum permitted under the specifications of the American Wood-Preservers' Association, and it is usually unnecessary to raise them above 150 lb. With woods of low compressive strength, or green timber that has been softened by steaming, it is often desirable to set the limit at 115 to 125 lb., since greater pressures may tend to cause collapse and checking of such material. With creosote, the temperature is usually required to average not less than 180°F. and not to exceed 210°F.

The proportion of the gross absorption of preservative recovered from the wood upon release of preservative pressure and application of final vacuum varies widely. It is influenced by the character and condition of the wood, the relation between the preliminary-air and preservative pressures, the temperature of the preservative, and, no doubt, various other factors. Recoveries as high as 50 to 60 per cent of the gross absorption are sometimes obtained, but those of 20 to 40 per cent are more common. The amount of oil recovered cannot be controlled at will by the plant operator, but he learns by experience what to expect under different conditions and controls the gross absorption accordingly. It is probable that, in many cases, the wood itself is compressed appreciably during the preservative pressure period, thus permitting extra oil to enter the cylinder and indicating higher gross absorptions than are actually obtained in the wood. The subsequent expansion of the wood, upon release of pressure, increases the recovery of oil. This effect is greater when high preservative pressures are used, especially with wood that has been softened by preliminary steaming.

The Rueping process has proved to be very practical and effective and, since its introduction in 1905, has been extensively employed in the United States. It is now the principal creosoting process in use in this country.

Another patent obtained by Rueping (U.S. 1,008,864, Nov. 14, 1911) covers the use of repeated applications of air pressure and vacuum, after the injection of the oil, for the purpose of recovering additional quantities of oil and of forcing the preservative deeper into the wood. This process appears to have found little, if any, commercial use.

LOWRY PROCESS

This empty-cell process was patented in 1906 by C. B. Lowry (U.S. pat. 831,450). In its general features, it differs from the Rueping process only in the fact that it does not involve the use of an initial air pressure above the atmospheric. The preservative oil is injected into the timber without any preliminary treatment other than such conditioning as may be required when green wood is to be impregnated. The air that is naturally present in the wood is compressed during the preservative-pressure period and serves to expel part of the injected oil when the pressure is broken and the final vacuum is drawn. The preservative temperature is generally required to average not less than 180°F. and not to exceed 210°F., and the maximum pressure is limited to 200 lb. per square inch. The length of time required to attain the specified pressure and the period for which it is held vary according to the kind of wood being treated and other conditions, such as the size and moisture content of the material; in general, the maximum pressure being used is maintained until the desired gross absorption is obtained. The final vacuum is usually held for a period of not less than 30 min. A diagram of the Lowry process is shown in Fig. 57.

The proportion of the gross absorption recovered, after the release of the preservative pressure and the application of the final vacuum, is naturally not so great as when a substantial preliminary air pressure is used (Rueping process), but it is definitely greater than in the full-cell (Bethell) treatment. With a given net absorption, therefore, the penetration obtained with the Lowry process is better than that secured with the Bethell and substantially the same as that gained with the Rueping treatment when very low preliminary air pressures are used. The Lowry process has an advantage in that the equipment for the full-cell method can be used without other accessories, whereas the Rueping process usually requires additional equipment, such as an air compressor and an extra cylinder or Rueping tank for the preservative or a suitable pump to force the oil into the cylinder against the air pressure. Because of its simplicity and recognized efficiency, the Lowry process is used extensively in this country.

MISCELLANEOUS PROCESSES USING PRESSURE

There are a number of processes that make use of pressure in one form or other, but in which the wood is not enclosed in treating cylinders. The following are among the more important of these:

Boucherie Process.—As originally patented in 1838 by Dr. Boucherie of France (Fr. pat. 11,061), this treatment consisted in attaching a bag or other container of preservative solution to a standing or a freshly cut tree, which had the bark, branches, and leaves still attached (15). The subsequent evaporation of moisture from the leaves drew the preservative into the sapwood of the tree trunk. The method was inconvenient, and the results were erratic, so that the process was changed through various steps to its present form, which is described essentially in British patent 1369, issued Dec. 14, 1855, to H. Mathis, for Dr. Boucherie. As now practiced, the Boucherie treatment is applied almost entirely to poles and consists in placing freshly cut, unpeeled timbers upon inclined skids, attaching watertight caps to the butt ends, and leading copper sulphate solution into the caps from a container, which is elevated about 25 or 30 ft. above the ground (Fig. 58). The hydrostatic pressure of the column of liquid against the butt end of a pole forces the preservative lengthwise through the sapwood, pushing the sap out of the other end of the timber. In a few days, the sapwood is completely permeated, but little or no penetration takes place in the heartwood. Only green wood can be treated in this manner.

Copper sulphate has been almost invariably employed as the preservative in this process, although other salt solutions will penetrate the timber as well. The blue vitriol has one advantage over colorless salt solutions in that it stains the wood and thus makes it easy for the operator, by examining a disk cut from the unconnected end of a pole, to determine when the timber has been sufficiently treated. Color tests can be used for some of the other preservatives, however. Preservative oils do not penetrate satisfactorily in either green or dry wood, when applied by this method.

In Europe, the Boucherie process was used extensively for many years in the treatment of poles but has now been largely displaced by the more effective pressure-creosoting methods. In this country, the U. S. Forest Service made some experiments with the method in 1911 and 1912, but it did not prove sufficiently advantageous to warrant commercial use.

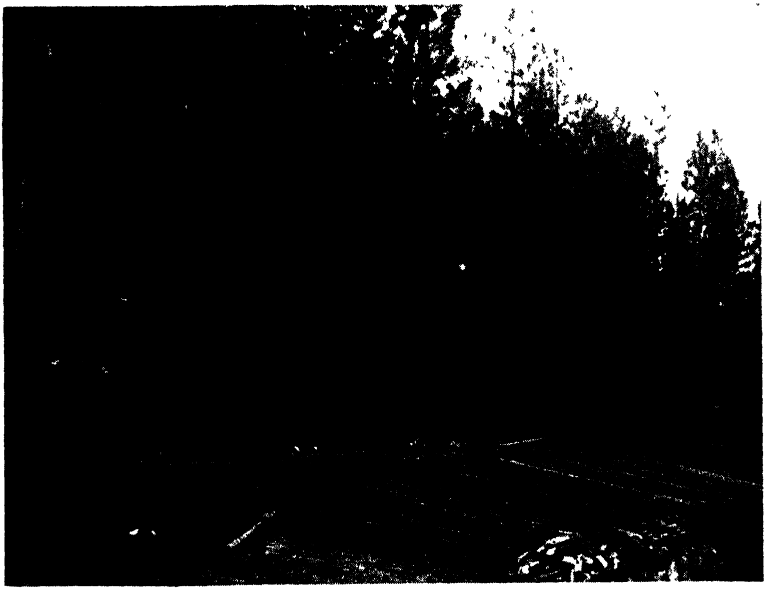

Fig. 58.—U.S. Forest Service experimental plant, used in 1912 for treating poles by the Boucherie process. (*U.S. Forest Service.*)

During very recent years, two American inventors have promoted somewhat different adaptations of the Boucherie process, in which improved caps and hose attachments are employed, preservatives other than copper sulphate are used, and the solution is forced through the wood by pump pressures greater than the hydrostatic force used by Boucherie. One of these new methods, known as the *Mineralized-cell treatment* and said to employ a solution of copper, arsenic, and zinc, is being promoted in the Pacific Northwest by the Mineralized Cell Wood Preserving Co., of Seattle, Wash. The company apparently also follows the old practice of obtaining pressure by means of an elevated solution tank. The other method, designated as the *Rice treatment* and using a preservative of undisclosed composition, was promoted in the North Atlantic states by George E. Rice, now deceased. As yet, neither of these modifications of the Boucherie process has been used to any great extent, although there are numerous commercial installations of poles and piles treated by the Mineralized-cell method.

Cobra Process.—This treatment, invented in Germany about 1920, is covered by numerous patents, including one issued to Herman Laube in 1922 (Brit. pat. 159,479) and another granted to Carl Schmittutz in 1924 (Ger. pat. 397,773). A special tool is used to inject a preservative paste into the wood at close intervals, and the process gets its name from the analogy of the instrument to a serpent's tooth. The tool consists of a long, sturdy needle, having an opening extending throughout its length and connected with a hollow handle, which is filled with preservative. The unpointed end of the needle is capped with a flat head, which is pounded with a wooden mallet or other hammer-like device to drive the point of the needle to a depth of several inches into the wood (Fig. 59). As the needle is withdrawn, a quantity of preservative paste is forced from the handle reservoir, through the needle, and into the hole left in the wood. The preservative is dissolved from the paste and gradually diffuses into the surrounding wood, provided there is sufficient moisture in the timber. The spacing of the holes is intended

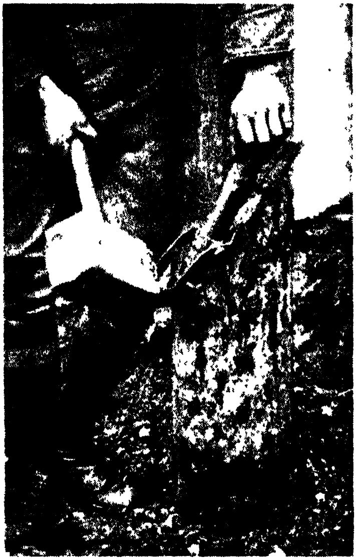

FIG. 59.—Treating a standing pole (in Germany) by means of the "Cobra" instrument.

to be such as to permit complete penetration of the wood between them. As an added protection to the timber, a preservative mixture containing some coal-tar creosote is thoroughly brushed over the surface of the treated section.

The instrument described above was used especially for the treatment of standing poles that had begun to decay. In such cases, the soil was dug away from the base of the pole, and the preservative injected over a section extending from 1½ ft. below to a like distance above the ground line. A considerably heavier type of apparatus was designed for treating new poles, in quantity, before installation. With this latter tool, the needle was forced into the wood by a lever, and the treatment could be carried on more rapidly than with the hammer-driven instrument. This heavier device also contained a larger reservoir for the preservative paste.

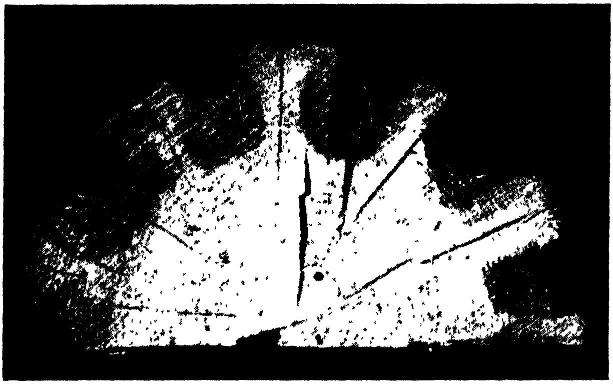

FIG. 60.—Cross section of a "Cobra-treated" pole in which incisions were placed too far apart. Dark, depressed areas show where insufficient diffusion permitted decay. (*Courtesy of A. Rabanus.*)

The Cobra process can be used with any preservative capable of being prepared in paste form and of diffusing through the wood when dissolved by water. In Germany, however, it was customary to use a mixture of fluoride-phenol-chromium salts, similar to Wolman salts. The process appears to have been first used in that country about 1921, and many thousands of standing poles were treated during the next few years. In some cases, the results obtained have been very good, while in others they have been unsatisfactory. Failure could often be attributed to careless or inadequate application of the paste, as, for example, when the incisions were spaced so far apart that the preservative did not thoroughly diffuse through the intervening wood. Figure 60 shows such a case, in which the wood between the incisions was destroyed by decay. It was found necessary to apply the preservative over the entire length of new poles, as these timbers decayed above the treatment when the injection was confined to the ground-line section. The Cobra process has apparently been largely abandoned in Germany but is evidently still employed to some extent in other European countries. It was never used commercially in the United States.

Pfister Method.—This treatment, patented in 1927 and again in 1930 by J. R. Pfister (U.S. pats. 1,629,302 and 1,742,726), is substantially the same as the Cobra process (lever instrument). The chief differences between the two methods appear to be in the details of construction and operation of the tools used for injecting the paste and, especially, in the form of the penetrating needle or chisel. They probably also differ in the preservatives used, but any paste of suitable consistency may be employed with either method. The Pfister treatment has been used to some extent in the United States during the last few years, for the treatment of standing poles and of wharf timbers already in place. Public records are not yet available to show just how effective the treatment is, but it should give satisfactory results, provided a good preservative is used, the holes are properly spaced, and the work is otherwise well done. Whether or not the method is sufficiently economical to warrant extensive use depends upon the cost per year of service obtained, in comparison with that for other treatments. Practically no information is available on this matter.

Pressure Treatment in Bored Holes.—A relatively simple method has been developed for the pressure treatment of bolt holes, bored through timber that has been previously impregnated with preservative. A tapered, threaded steel plug is screwed tightly into one end of a hole, and a somewhat similar device, with an opening throughout its length and provided with a hand pump and a cup for holding creosote or other liquid preservative, is fitted securely into the other end (Fig. 61). The preservative is fed from the cup into the opening in the injector and pumped into the hole, until considerable pressure is built up. In treating holes that do not pass entirely through the timber, only the device fitted with the cup and pump is used. This type of treatment provides a much more thorough impregnation of the wood surrounding the hole than can be obtained by any nonpressure method. Penetration is greatest, of course, in the longitudinal direction (with the grain) from the ends of the fibers exposed by the boring. The tapered shapes of the plug and the injector make it possible to fit the apparatus in holes of various sizes.

A somewhat similar method has been used for protecting sills, joists, and other house timbers already in place against termite attack. In this, holes are bored into, but not quite through, a timber, and a suitable preservative is forced into these openings.

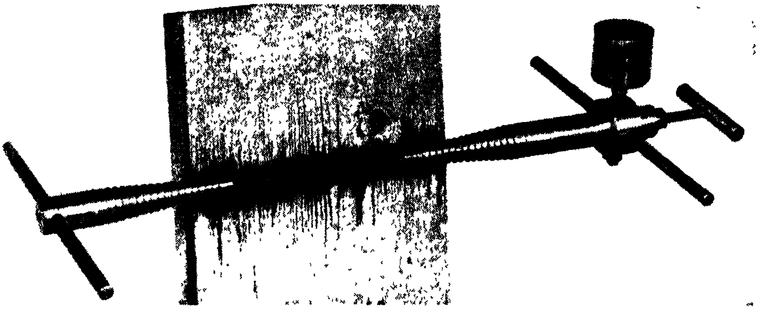

FIG. 61.—Apparatus for pressure-creosoting bolt holes. (*Greenlee Bros. and Co.*)

A special nozzle is used which fits tightly into the holes, making it possible to build up a high pressure and thus obtain considerable penetration with the grain of the wood. The side penetration (across the grain) from the holes is probably slight, but by properly spacing the openings, so as to take full advantage of end penetration, a considerable proportion of the wood can be impregnated.

Pressure Treatment of Pile Heads.—Untreated wood, exposed when pile heads are cut off to grade, may be pressure treated by a method developed by E. F. Hartman (7). This involves the use of a heavy iron cap, which is fastened over the head of a pile in such a way as to form a chamber, into which creosote may be admitted under pressure and forced longitudinally into the pile to a considerable depth. Penetrations of several feet are reported in the sapwood of southern pine piles. It is stated by Hartman that the rate of absorption and penetration proceeds steadily over a long period of time, rather than falling off rapidly, as it does in the treatment of wood entirely enclosed in a cylinder. Despite its apparent effectiveness, this method appears to have found very little use, probably because it is not very convenient or rapid.

Hartman has suggested the use of the process for treating the above-water parts of piles in fresh water or in foundations, thus avoiding the waste of heavy treatment in the submerged parts, which do not need it.

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CHAPTER VII

FACTORS AFFECTING PENETRATION AND ABSORPTION

While the effectiveness and ultimate economy of any given preservative treatment are determined eventually by the service life of the timber involved, the immediate criteria of the adequacy of the treatment are the amount of preservative absorbed and retained by the wood and the depth to which it has penetrated. Uniformity of distribution of preservative throughout the treated zone is also significant but is less readily determinable than the other two factors.

Experience has shown that the amount of preservative necessary for adequate protection is governed largely by the specific use to be made of the wood. Thus, in the case of piles and other products to be used in waters infested with marine borers, maximum absorption is desired, and the timber should be made to absorb all the preservative it will hold. On the other hand, with such products as crossties, poles, construction timbers for buildings, and the like, the conditions of service are such that much lighter absorptions are not only adequate but often necessary for economic and other reasons.

Absorption in itself is not an adequate index of the efficiency of a given treatment, however, for it is a well-recognized fact that there may be marked differences in the depth to which a preservative penetrates individual timbers having approximately the same unit absorption. Penetration is properly considered to be a better measure of the effectiveness of treatment than absorption, although the importance of having a sufficient concentration of preservative in the treated region should not be overlooked. Inadequately penetrated wood may be subject to early failure, as the result of the extension of checks beyond the treated zone or the actual mechanical breakdown of the impregnated shell. A recent study (7) of the relation between penetration and decay in creosoted southern pine poles showed that 95 per cent of the failures found were in timbers in which the creosote had penetrated less than 1.8 in. and less than 60 per cent of the sapwood thickness; no failures were found in poles that had been penetrated more than 2.1 in. and 75 per cent of the sapwood thickness.

The impregnation of timber by preservatives is influenced by a considerable number of factors, which for convenience may be classified in three groups, according as they relate to (*a*) the anatomy of the wood, (*b*) the preparation of the timber, and (*c*) the treating procedure. Certain of these factors, especially those relating to treating procedure, are susceptible to control and may be varied as found necessary to obtain the desired results. Others, and particularly those pertaining to the anatomy of the wood, are inflexible and may definitely complicate the problem of securing adequate and uniform treatment.

In considering the factors that influence penetration and absorption of preservatives in wood, it should be borne in mind that, in most processes, the preservative is not free to flow through a given timber. A conspicuous exception is found in the Boucherie process, in which the liquid is applied to one end of a pole and moves through the sapwood with relative ease until it reaches the other end. In practically all other methods of treatment, and notably in those that involve the impregnation of wood in a closed cylinder, the preservative solution moves toward the interior of the timber from all surfaces. In the Boucherie treatment, the water and air can escape ahead of the preservative; but in the closed-cylinder processes, they remain in the wood and are surrounded and compressed by the entering preservative.

When wood is treated in closed cylinders, the effectiveness of the applied pressure decreases as the time of treatment increases and the available space becomes more nearly filled with preservative, until finally the amount of solution entering per unit of time becomes negligible, and the wood is said to be treated "to refusal." At this point, there may be a considerable pressure gradient between the surface and the interior of the timber, but the resistance of the wood to penetration, as influenced by the "friction" on the entering solution plus the back pressure of the preservative that has already entered, prevents further absorption. In very receptive wood, such as the dry sapwood of the pines, the gradient may not be very steep, and the pressure may be relatively high even at the center of the timber. On the other hand, in wood that is highly resistant to penetration, such as the heartwood of white oak, red gum, and mountain-type Douglas fir, the gradient may be so sharp that the pressure decreases almost to zero within a fraction of an inch from the surface. Any pressure that develops in the interior of such refractory timber is caused by the compression of the wood itself or by the heating of the imprisoned air rather than by the transfer of the external pressure through openings in the wood.

In timber that has a high moisture content, preservatives soluble in water can enter the wood by diffusion, without the application of external pressure. In this case, the effective force is the osmotic pressure, which tends to produce a concentration of chemical in the water within the wood equal to that in the water surrounding the wood. In seasoned timber, on the other hand, the chemical cannot enter the wood by osmosis but must be carried in with the water.

ANATOMY OF THE WOOD

One of the most perplexing problems relating to the treatment of timber with preservatives is the varying resistance that different species, and even different pieces of the same kind of wood, offer to impregnation. Some timbers may be penetrated with relative ease; others are more or less intermediate in the facility with which they absorb preservatives; while still others are extremely difficult to treat. In some instances, the precise causes of these recognized differences in permeability are obscure. But in most cases, the variations are known to be associated, at least in part, with definite anatomical distinctions among the woods concerned. It is also quite possible that the physical and chemical properties of the woods may play an important role in determining susceptibility to impregnation in individual species.

The various commercial woods are commonly segregated into two broad groups: (*a*) the *softwoods*, or conifers (gymnosperms), comprising the pines, Douglas fir, spruces, larch and tamarack, hemlocks, true firs, redwood, southern cypress, cedars and junipers, and yew; and (*b*) the *hardwoods* (angiosperms), including the oaks, chestnut, elms, ashes, hickories, maples, birches, beech, gums, and a considerable number of other woods. These general terms softwood and hardwood are somewhat misleading, since they do not refer specifically to the comparative densities of the two groups of wood, but they are universally accepted in the timber trade and have acquired definite technical and legal recognition.

Anatomically the two groups of wood are quite distinct.* The softwoods are comparatively homogeneous, consisting essentially of two main elements, or cell forms: *wood tracheids*, which are concerned in the living tree with the dual functions of sap conduction and mechanical support; and *rays*, which serve chiefly for the storage and conduction of elaborated food materials. In certain softwoods, the wood is characterized by the presence of vertical and radial intercellular canals, or *resin ducts*. *Wood parenchyma* cells, other than those which surround and limit the vertical resin ducts, also occur in some softwood species, but they are sparsely developed at best.

The hardwoods, on the other hand, are relatively heterogeneous in their structure, having a greater complexity of cell forms, associated with a more marked division of labor in the living tree, than is the case in the softwoods. The ascent of sap in the stem is facilitated by tubelike structures, known as *vessels;* mechanical support is provided by *wood fibers;* and food storage and conduction are functions of the rays and also of the wood parenchyma cells, which are quite well developed in some species. The ordinary tracheids, which make up the great bulk of the softwoods, may be considered, for the purposes of this text, as entirely lacking in the hardwoods.

In the following paragraphs, these several softwood and hardwood elements are considered in relation to their recognized effect on the impregnation of wood with preservatives.

WOOD TRACHEIDS

The ordinary tracheids, which constitute the great bulk of the wood of softwood species, are hollow, axially elongated, imperforate cells, with characteristic, small gaps or recesses (pits) in their side walls (Fig. 62). These cells are quite variable in length, even in the same species, and range from about 0.7 to over 9 mm. in the common American conifers; the general average length for all species is approximately 3.5 mm., or 0.14 in. (25). They are about a hundred times as long as wide, the inside (cell cavity) diameter range being given as 0.005 to 0.05 mm. (12). For the most part, the tracheids are arranged in definite radial rows and are more or less square or rectangular in cross-sectional outline. In some species, such as the white pines, they are practically all thin walled and have relatively large lumina; while in other woods, notably Douglas fir and the southern pines, the cells formed during the latter part of the growing season are definitely thick walled and have comparatively narrow cavities.

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* Marked variations in wood structure are also found between individual softwoods and hardwoods, but no attempt has been made to discuss these features in any detail in this text. For a comprehensive discussion of the anatomy of wood, the reader is referred to Record (25).

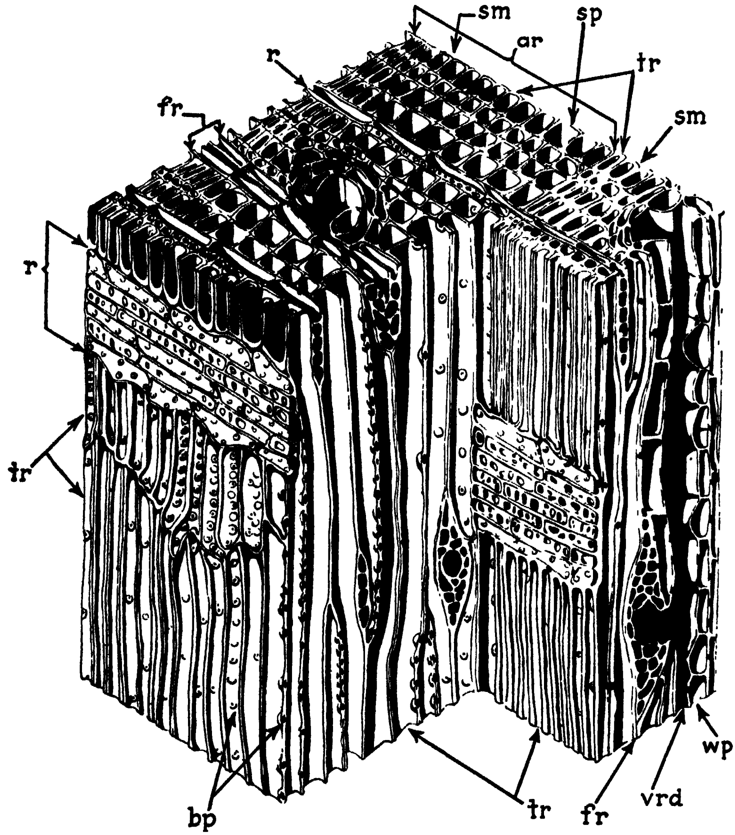

FIG. 62.—Drawing of a block of softwood, greatly enlarged, showing wood tracheids *tr*, bordered pits *bp*, vertical resin ducts *vrd*, normal rays *r*, fusiform rays *fr*, wood parenchyma *wp*, annual growth ring *ar*, spring wood *sp*, and summer wood *sm*. (*U.S. Forest Products Laboratory.*)

In timbers of this latter class, the wood produced during a given year is clearly differentiated into open *spring-wood* (early-wood) and relatively dense *summer-wood* (late-wood) layers (Fig. 62).

The impregnation of softwood timbers is largely dependent upon the movement of preservatives through the cavities of the tracheids, passage from cell to cell being effected through valve-like structures, known as *bordered pits*, which occur as complementary pairs in adjacent tracheid walls. In a pit of this type (Figs. 63*A* and 64*B*), that portion of the thickened (secondary) cell wall which constitutes the so-called *border* projects out over the *limiting membrane* in a saucer-shaped, or domelike, fashion to form an intervening *pit chamber*. Connecting this chamber with the cavity (lumen) of the tracheid is a constricted opening in the overhanging border, known as the *pit canal*. The limiting pit membrane, which serves as a permeable partition through which preservatives pass in going from one tracheid to another, is thickened at the center to form a disk- or lens-shaped *torus*, of somewhat larger diameter than the circular aperture of the pit canal. Since the membrane is more or less flexible, it may be pushed or pulled against the aperture of the pit canal so that the torus more or less effectively seals the pit against the passage of liquids. As seen in surface view (Figs. 63*B* and 64*A*), much of

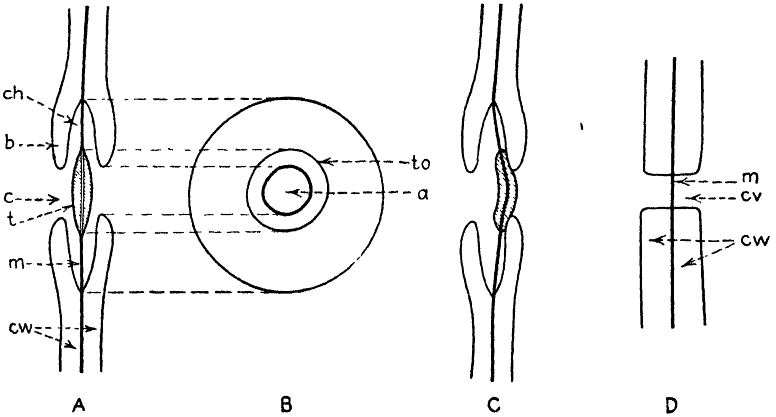

FIG. 63.—Diagrammatic sketch of pits in wood cells, greatly enlarged. *A*, section of unaspirated bordered pit, as seen in profile view, showing border *b*, pit canal *c*, pit chamber *ch*, cell walls *cw*, limiting pit membrane *m*, and torus *t*; *B*, surface view of bordered pit shown in *A*, showing aperture of pit canal *a* and outline of torus *to*; *C*, profile view of aspirated bordered pit; *D*, profile view of simple pit, showing cell walls *cw*, pit cavity *cv*, and pit membrane *m*.

the detail of the pit structure is obscured, the aperture of the canal appearing as a circular, or at times somewhat lenticular, opening within the rounded outline of the pit; not infrequently the circular outline of the torus is also evident.

That portion of the pit membrane not covered by the torus was generally considered to be entire, until Bailey (2) demonstrated microscopically that it is actually perforated with minute openings and thus permeable to heavy oils and other viscous liquids and even to finely-divided solids. These findings have been substantiated by dynamic physical methods of studying the capillary structure of softwoods (27), which have also indicated that the *maximum* effective diameters of the openings range from 63 to 174 mμ (0.000063 to 0.000174 mm.) in the investigated species (Sitka spruce, Alaska cedar, western red cedar, mountain-type Douglas fir, and ponderosa pine); the *average* diameters in individual wood specimens were found to vary from 11 to 23 mμ in western red cedar and from 14 to 21 mμ in Alaska cedar.

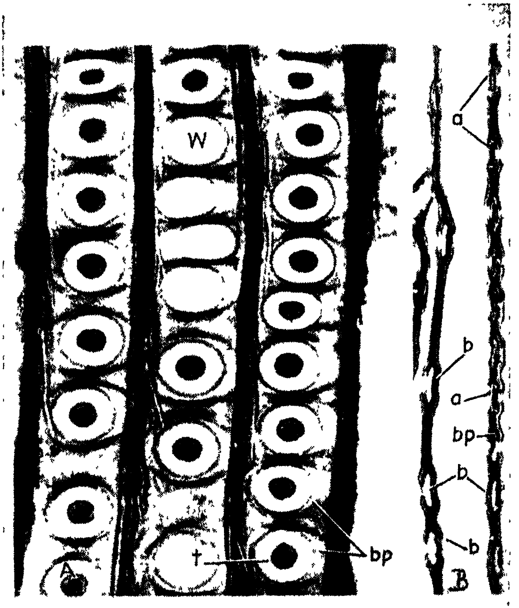

Fig. 64.—Photomicrograph, showing greatly magnified bordered pits *bp* in surface *A* and profile *B* views. The white areas *W* are pits, in which the torus *t* was not exposed in sectioning the wood. *B* shows both unaspirated *a* and aspirated *b* pits. (*U.S. Forest Products Laboratory.*)

These openings, while in general somewhat smaller than the resolving limit of the microscope, are sufficiently large to permit the passage of colloidal solutions containing very fine particles, such as the carbon suspension used by Bailey in his microscopic investigation. It is evident, therefore, that the permeability of the pit membrane will be dependent upon its porosity, surface area, and thickness (28). It has also been suggested that, during the pressure-impregnation period, the force exerted by the liquid on the pit membranes causes them to stretch, with a resultant increase in the size of the perforations (6); furthermore, since steaming timber prior to impregnation makes the wood substance more plastic, one investigator suggests that it may possibly increase the effect of the subsequent application of pressure in distending the membranes and enlarging the openings (12).

In order that bordered pits may serve effectively in the penetration of wood by a preservative, it is essential that they remain unaspirated, *i.e.*, with the partitioning membranes maintained in the central position (Figs. 63*A* and 64*B*). Otherwise, the aspiration, or closing, of the pits (Figs. 63*C* and 64*B*) will retard or prevent the movement of the liquid through the wood, depending upon the extent to which it occurs (10, 11) and possibly also upon how firmly the tori are fixed against the canal apertures. Microscopic examination of practically any untreated softwood will show that aspiration is a very general condition, although the proportion of pits that are closed may vary widely in different woods and even in different parts of the same timber. The pits are largely concentrated in the overlapping portions of longitudinally adjacent tracheids, thus facilitating the upward movement of sap in the living tree, and vary in number from about 30 to 300 in cells having an average length of 3.0 mm. and a diameter of about 0.03 mm. (28). If a continuous passage of preservative is to be obtained through a given tracheid, it is imperative that at least two expediently located pits remain open, one for the ingress and the other for the egress of the liquid. Investigations have disclosed that such a condition may actually be the exception in spring-wood tracheids, particularly in certain refractory species (see Table VIII); as a result, many or even most of the tracheids will serve to block rather than facilitate the movement of preservative through the wood. It might be expected that the pressures used in injecting preservative into a timber would tend to displace the still centrally-located membranes and thus close such pits as have remained unaspirated, but experimental work (15) has indicated that this is not the case.

There is no generally accepted theory as to the precise cause of pit closure, but certain investigations (10, 24) have indicated that the phenomenon is definitely associated with the drying of the wood. Thus, study of the relation of moisture content to extent of pit closure in the sapwood of several British-grown softwoods (Douglas fir, Scots pine, and Corsican pine) showed that, while some aspirated pits are to be found even in unseasoned material, the number increases gradually as the amount of free water in the cell cavities decreases, until the moisture content approaches the *fiber-saturation point.** At this point, pit closure becomes quite general, especially in spring-wood tracheids. In explanation of this phenomenon, it is suggested that, as the cavity of a tracheid becomes filled with air, a meniscus is formed between the canal aperture and the membrane in each pit in the wall of the cell; the resultant surface tension tends to pull the torus over against the aperture, since a compensating force is generally not set up in the complementary pit in the wall of the adjoining tracheid. (24.)

While there is no precise information as to the extent to which wood should be air seasoned prior to preservative treatment, the apparent correlation between moisture content and pit closure suggests that, for sapwood at least, there may be an optimum degree of dryness for penetration. However, the relationship between moisture content and penetrability may also be influenced by changes in the size of the membrane openings in the unaspirated pits. These openings have been found to become larger as the wood dries below the fiber-saturation point (29). The initial drying also appears to cause checks to form across the pits.

In those softwoods in which seasonal layers are clearly differentiated, the relatively dense summer wood is generally recognized as being easier to impregnate than the more porous spring wood, despite the appreciably greater average number of pits per tracheid in the spring wood (Table VIII). As a result, it is difficult to obtain uniform distribution of preservative in woods

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*** See footnote on page 30 for explanation of the term fiber-saturation point.**

like southern pine and Douglas fir, and creosote treatments often appear to be concentrated in bands (as seen on cross section) or streaks (longitudinal section). Determination of the absorption of creosote in loblolly pine showed that the summer wood contained 80 per cent more oil than the spring wood (30). As pointed out by MacLean (23), in such cases as these, the less thoroughly impregnated spring-wood layers are usually adequately protected by the adjacent layers of well-treated summer wood; furthermore, there may be a subsequent diffusion of preservative from the summer wood into the spring wood. On the other hand, Buckman (5) determined that in freshly treated southern pine poles the creosote concentration was usually higher in the spring wood than in the summer wood, especially in the outer layers of poles having average absorptions of 8 lb. per cubic foot or more; although spring wood is more resistant to penetration than summer wood, the former, because of its greater air space, can hold much more creosote than the latter, when both are saturated.

The superior treatability of the summer wood appears to be associated, at least in part, with the relative proportion of unaspirated pits found in the two portions of the growth layers. Investigations of such native woods as Douglas fir (10), western larch and lodgepole pine (11), and corkbark fir (20) have revealed the fact that pit closure is less extensive in the summer wood than in the spring wood of these species. This general condition is further emphasized by the data incorporated in Table VIII,

TABLE VIII.—CONDITION OF TRACHEID PITS IN AIR-DRIED, BRITISH-GROWN SOFTWOODS

Kind of wood	Average number of pits per tracheid		Average percentage of pits unaspirated		Average number of unaspirated pits per tracheid	
	Spring wood	Summer wood	Spring wood	Summer wood	Spring wood	Summer wood
European larch...	90	8	1	29	0.9	2.3
Norway spruce...	90	25	7	31	6.3	7.8
Corsican pine....	49	12	1	40	0.5	4.8
Scots pine........	70	17	2	66	1.4	11.0
Douglas fir.......	92	8	1	25	0.9	2.0

which were obtained in a microscopic study of five air-dried British-grown softwoods (24).

In explanation of these observed results, it is suggested that, because of their smaller size, thicker overhanging borders, and presumably more rigid membranes, the summer wood pits offer more resistance to the forces that tend to produce aspiration than do those of the spring wood.

RESIN DUCTS

Resin ducts are narrow, intercellular canals, of indeterminate length, which form an intercommunicating system of vertical (axial) and radial passages in certain softwoods (Fig. 62). They are most abundantly developed in the pines but also occur normally in the spruces, Douglas fir, western larch, and tamarack.* These openings in the wood are not cells and accordingly have no limiting walls of their own, being surrounded by one or more layers of wood parenchyma cells (vertical ducts) or confined in enlarged, or fusiform, rays (radial ducts).

In the pines, the vertical resin ducts are generally of sufficient size to be readily discernible with the unaided eye, appearing as minute holes or spots on cross section and as fine lines or scratches on longitudinal surfaces; they are comparatively numerous and fairly well distributed throughout the growth rings. In the other enumerated softwoods, the axial canals are relatively small and indistinct (at times invisible without a hand lens) and are more irregularly disposed. Furthermore, they differ from the ducts in the pines in being definitely constricted at intervals. The radial resin ducts are smaller than the vertical canals, which they frequently intersect, but more uniformly distributed in the wood.

Because of their canal-like character, resin ducts may be regarded as potential channels for facilitating the movement of preservatives into wood during impregnation. Thus, vertical ducts may be expected to improve the penetration of a liquid from the ends of a piece, while radial ducts will presumably assist in the penetration from the tangential (flat-sawed) faces. While this is generally recognized as being the case, particularly in the pines, experience has indicated that some of the softwoods possessing normal resin canals are fully as difficult to impregnate as others that contain no ducts (Table IX). The effectiveness of the canals in aiding in the treatment of wood is naturally dependent upon their size, number, and distribution as well as upon their continuity. The last-named factor is influenced, in turn, by the extent to which the vertical and radial ducts are obstructed by hardened resin or other extraneous materials or by tylosoids* and, in the spruces, Douglas fir, western larch, and tamarack, by the degree and frequency of constriction of the vertical canals.

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* Vertical resin ducts are sometimes found in individual pieces of certain other softwood species, but their formation in such woods invariably results from injuries sustained by the living trees. These traumatic ducts are distinct from the normal resin canals in that they are grouped in definite, short to long, tangential series (parallel to growth rings, as seen on transverse section), whereas the normal ducts are isolated or at times disposed in small groups of two or three.

In woods containing normal resin ducts, effective treatment depends not alone upon the penetrability of the canals but also upon the permeability of the cells adjoining them. This applies not only to the wood or ray parenchyma cells immediately surrounding the canals but also to the neighboring wood tracheids. When the adjoining parenchyma cells and tracheids are relatively permeable, as is apparently the case in most species of pine, at least in the summer wood, the presence of numerous, well-distributed, and relatively open resin ducts makes possible the rapid conduction of preservative below the surface of the timber and its subsequent distribution into the surrounding cells. On the other hand, in the heartwood of species such as tamarack and mountain-type Douglas fir, the ducts may be penetrated to a greater or lesser extent, but so little preservative enters the adjacent wood cells that the resultant treatment is generally inferior.

VESSELS

Vessels, which form a characteristic part of the structural pattern of the hardwoods (Fig. 65), are axially disposed, tubelike structures of indeterminate length, which function in the process of sap conduction in the living tree. They are formed by the fusion of vertical series of cells, known as *vessel members*, which differ from the other elements in wood in not being entirely enclosed by cell walls. Instead, they have definite and relatively large perforations at both ends, so that the cavities of the vertically contiguous members in a single vessel open directly upon one another. Thus, the longitudinal movement of liquids and gases is facilitated in the hardwoods, since these substances do not have to pass through pit membranes at frequent intervals. On the other hand, lateral movement from one vessel to another adjoining, or from a vessel to a different type of cell, takes place primarily through the pit-pairs in the adjacent walls. These are quite variable in structure and appearance. Even when fully bordered, as between contiguous vessels, the pits are distinct

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* See page 244 for explanation of tylosoids.

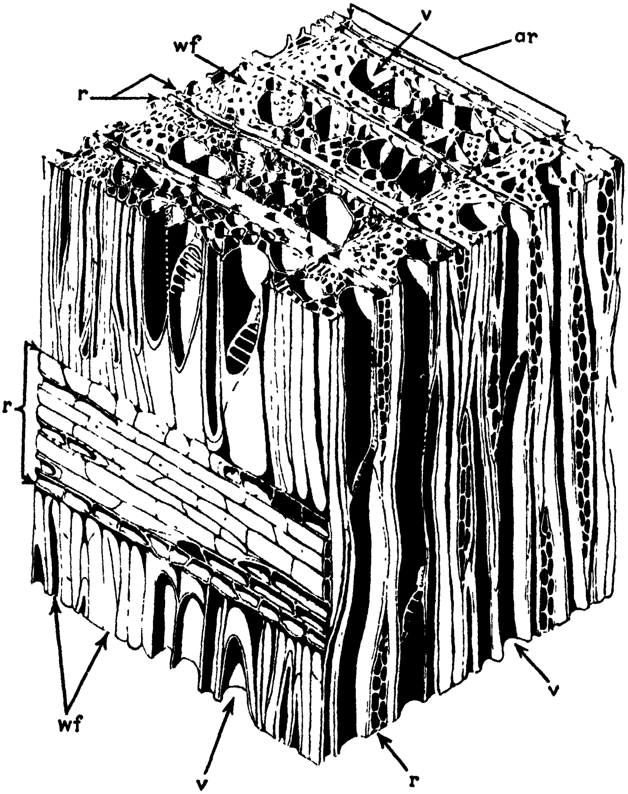

FIG. 65.—Drawing of a block of hardwood, greatly enlarged, showing vessels *v*, wood fibers *wf*, rays *r*, and an annual growth ring *ar*. (*U.S. Forest Products Laboratory.*)

in a number of respects from those in the softwood tracheids; they are generally much smaller than the tracheid pits and, since they do not exhibit the characteristic valvelike action of the latter, always remain unaspirated.

Because of their tubelike structure, vessels serve as natural passages for the conduction of preservatives in the direction of the grain of the wood. However, their effectiveness is dependent upon their freedom from extraneous materials and tyloses* and also upon their size, number, and distribution, factors that vary over wide limits in different hardwood species. Depending upon the arrangement of the vessels, the hardwoods are generally classified as either *ring porous* or *diffuse porous*. In the former group, which includes the oaks, ashes, hickories, and elms, the pores† in the spring wood are usually definitely larger, and in some cases also more numerous, than those in the summer wood. In diffuse-porous hardwoods, such as the maples, birches, beech, gums, basswood, and cottonwoods, the pores are more nearly the same size and more regularly dispersed throughout the growth rings. It naturally follows that, when the vessels are unobstructed, preservative distribution tends to be more uniform in diffuse-porous than in ring-porous timbers; in the latter, the spring wood may be expected to receive heavier treatment than the summer wood.

In closing this brief discussion of vessels, which are generally regarded as the most significant of the anatomical factors affecting initial penetrance of hardwoods, it may be pointed out that the extent to which these elements contribute to the general distribution of preservatives (uniformity of treatment) is also dependent upon the permeability of the surrounding wood. As is the case with resin ducts in softwoods, the inability of the preservative to force its way or diffuse out of the main passageways into the adjoining cells may result in a very spotted treatment. While the lateral movement of liquid out of the vessels is presumably dependent, at least in part, upon the character of the pitting into the contiguous cells, little or no precise information is available concerning this phase of the subject of penetration.

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* See page 243 for explanation of tyloses.

† The term *pore* is commonly used for convenience to designate the cross section of a vessel member, as seen on the end of a piece of wood.

WOOD FIBERS

Wood fibers constitute the bulk of the woody tissue in most hardwoods, although the proportion of these cells to the other elements may vary over wide limits in different species. Like the tracheids of the softwoods, they are axially elongated cells, with closed ends and more or less definitely thickened walls (Fig. 65). They are relatively short, however, seldom exceeding 2.0 mm. in length, and, since their primary function is that of mechanical support, are not especially adapted to the conduction of liquids. As a rule, the pits in the side walls are relatively small and irregular in their distribution; furthermore, they are simple or have only vestigial borders in many species. Although the distinctly bordered fiber pits, like those in the vessel members, always remain unaspirated, they do not compare with tracheid pits as potential passages for liquids. This may be due to differences in the limiting membranes, which are generally regarded as being unperforated in the fiber pits, although this fact is by no means definitely established.

In general, it may be said that wood fibers are not important factors in the initial penetration of preservatives, although their relative permeability may have a marked influence on the subsequent spread of liquids from vessels and other possible points of concentration. In some woods, however, the fibers apparently play a more important role in impregnation than the vessels. This is notably the case in the heartwood of hickory (9, 31), which is considered as being only moderately difficult to impregnate, despite the fact that the vessels in the spring wood are closed by tyloses and those in the summer wood are small and few in number. By way of contrast, the fibers in the heartwood of white oak are far less permeable (9, 23).

RAYS

The rays are ribbonlike aggregations of relatively small cells, extending radially in the wood (Figs. 62 and 65). They are concerned in the living tree with the storage and radial conduction of plant-food materials and, in some softwoods at least, may have a secondary water-conducting function. They are essential features of the anatomy of both softwoods and hardwoods but exhibit a marked variation in general appearance and structure, not only between the two classes of timber but within the individual groups as well.

The softwood rays, as a group, are so small as to be practically indiscernible to the unaided eye. As seen in tangential or end view (flat-sawed surface), they are one cell wide for the most part, although the fusiform rays, with their contained resin ducts, of necessity have definitely enlarged median portions (Fig. 62). They range from 1 to 20, or in some cases up to 50, cells high. The hardwood rays, on the other hand, are extremely variable in size and visibility. In some cases, as in willow and cottonwood, they are no larger than in the softwoods; while in other species, such as the various oaks and sycamore, at least part of them are so large and conspicuous that they give a definite and characteristic pattern to the wood. The large rays in the white oaks, while making up only a small percentage of the total number of rays in the wood, may be as many as 50 cells wide and several hundred cells (up to 5 in.) high.

Hardwood rays are relatively simple in their general structure, being composed entirely of parenchyma cells. Communication between the adjoining ray parenchyma cells is provided by simple pit-pairs in the common walls of contact. These simple pits are distinct from the bordered structures in several respects but chiefly in that they do not exert a valvelike action. They are devoid of any overarching borders and pit chambers (see Fig. 63*D*), and their limiting membranes are not provided with thickened tori. Furthermore, the presence of perforations in the membranes has never been demonstrated, the interchange of solutes in the living tree presumably being accomplished entirely by the process of osmosis. There is no evidence that the rays are of any assistance in facilitating the penetration of preservatives in hardwoods; in fact, it is stated (31) that in woods like oak, hickory, and sycamore they offer conspicuous resistance to impregnation, in contrast to the surrounding tissues. This is probably to be expected, not alone because of the nature of the simple pits but also as a result of the relatively small size of the cells and the fact that they are commonly obstructed by such substances as dried protoplasm, stored food materials, and various other extractives.

In a number of native softwoods, the rays are largely, if not entirely, composed of ray parenchyma cells, and, while definite experimental data are lacking, they are not considered to play a significant part in the penetration of liquids. But in the pines, and to a lesser degree in certain other softwoods, the rays also contain water-conducting cells (ray tracheids), which are characterized by bordered pits and devoid of visible contents and, consequently, may be expected to facilitate the radial movement of preservatives into the wood (from the flat-sawed surfaces). This was found to be the case in investigated specimens of pine and spruce (30). Finally, as pointed out in the previous discussion of resin ducts, the fusiform rays, which characterize the wood of the pines, spruces, larch, tamarack, and Douglas fir, may also aid in the radial penetration of preservatives, at least in those cases in which the contained horizontal resin ducts are unobstructed. Bailey (3) suggests that the readily penetrable rays may be of some significance in conducting preservatives through localized zones of wood tracheids, as from one band of permeable summer wood to another. However, even under the best conditions, the rays probably play only a subordinate role in the impregnation of softwoods.

WOOD PARENCHYMA

In addition to the horizontally disposed ray parenchyma cells, most woods contain vertical strands of longitudinally elongated cells, which are also parenchymatous in nature, being concerned with the axial distribution of food materials in the living tree. Such elements, which are designated as wood parenchyma cells, are more or less abundant in certain woods and poorly developed or entirely lacking in others. Among the softwoods, they are generally diffuse and not densely aggregated, other than around vertical resin ducts (Fig. 62) and in wound tissue; in those hardwoods in which they are well developed, they may form definite sheaths around the vessels or make up various patterns on the cross sections of the woods. The wood parenchyma cells are comparable to the ray parenchyma in many respects, including the nature of their pitting, and apparently do not aid in the initial penetration of wood by liquids. However, the permeability of the cells that limit the vertical resin ducts in the softwoods and surround the vessels in certain of the hardwoods may have a definite influence on the subsequent spread of preservatives from these channels of distribution.

SAPWOOD AND HEARTWOOD

During the early life of a tree, the wood that is formed is physiologically active and constitutes what is designated as the *sapwood.* But as the trunk and larger branches increase in diameter, with the annual increment of new sapwood layers on the outside of the already existing wood, the extreme interior portion sooner or later ceases to function, except mechanically, and also undergoes certain other changes, with the result that a more or less clearly differentiated inner core of *heartwood* is formed. With the continued diameter growth of the tree, the thickness of the heartwood increases while that of the sapwood remains approximately the same. As a result, large trees usually contain only relatively thin layers of sapwood, much of which is removed in sawing or hewing operations. However, other factors, such as the species involved and the conditions under which the trees are grown, may also have a significant effect on the relative amounts of these two types of wood.

As a general rule, it may be said that sapwood can be impregnated with relative ease, while heartwood is resistant to the penetration of preservatives. Conspicuous exceptions are noted, however, for in eastern hemlock, the true firs, and the spruces, the sapwood is nearly as difficult to penetrate as the refractory heartwood (23); while in ponderosa pine, the red oaks, and black and tupelo gum, even the heartwood takes treatment readily. Variation with respect to penetrability is especially marked in the heartwood, as is indicated by the data incorporated in Table IX. This tabulation is based on observations of actual commercial treatments, as well as the results of laboratory experiments. Because of the numerous variables that must be considered, it is not possible to do more than classify the woods in this general way; consequently, the arrangement of species within a group is not intended to indicate the specific relative resistance of the individual woods.

As indicated in Table IX, while the heartwood of a few softwoods and a considerably larger number of hardwoods can be impregnated with relative ease, that of most species is decidedly more difficult to penetrate satisfactorily. In fact, in a few very important commercial woods, notably white oak, red gum, mountain-type Douglas fir, and western red cedar, the heartwood

TABLE IX.—CLASSIFICATION OF AMERICAN WOODS WITH RESPECT TO HEARTWOOD PENETRABILITY (23)

Softwoods	Hardwoods
Group 1. Heartwood Easily Penetrated	
Bristlecone pine, *Pinus aristata*	Basswood, *Tilia glabra*
Pinon, *Pinus edulis*	Beech (white heartwood), *Fagus grandifolia*
Ponderosa pine, *Pinus ponderosa*	Black gum, *Nyssa sylvatica*
	Green ash, *Fraxinus pennsylvanica lanceolata*
	Pin cherry, *Prunus pennsylvanica*
	River birch, *Betula nigra*
	Red oaks (except blackjack*), *Quercus* spp.
	Slippery elm, *Ulmus fulva*
	Sweet birch, *Betula lenta*
	Tupelo gum, *Nyssa aquatica*
	White ash, *Fraxinus americana*
Group 2. Heartwood Moderately Difficult to Penetrate	
Douglas fir (coast type), *Pseudotsuga taxifolia*	Black willow, *Salix nigra*
Jack pine, *Pinus banksiana*	Chestnut oak, *Quercus montana*
Loblolly pine, *Pinus taeda*	Cottonwood, *Populus* spp.
Longleaf pine, *Pinus palustris*	Largetooth aspen, *Populus grandidentata*
Norway pine, *Pinus resinosa*	Mockernut hickory, *Hicoria alba*
Shortleaf pine, *Pinus echinata*	Silver maple, *Acer saccharinum*
Western hemlock, *Tsuga heterophylla*	Sugar maple, *Acer saccharum*
	Yellow birch, *Betula lutea*
Group 3. Heartwood Difficult to Penetrate	
Eastern hemlock, *Tsuga canadensis*	Hackberry, *Celtis occidentalis*
Engelmann spruce, *Picea engelmannii*	Rock elm, *Ulmus racemosa*
Lowland white fir, *Abies grandis*	Sycamore, *Platanus occidentalis*
Lodgepole pine, *Pinus contorta*	
Noble fir, *Abies nobilis*	
Sitka spruce, *Picea sitchensis*	
Western larch, *Larix occidentalis*	
White fir, *Abies concolor*	
White spruce, *Picea glauca*	
Group 4. Heartwood Very Difficult to Penetrate	
Alpine fir, *Abies lasiocarpa*	Beech (red heartwood), *Fagus grandifolia*
Corkbark fir, *Abies arizonica*	Blackjack oak, *Quercus marilandica**
Douglas fir (mountain type), *Pseudotsuga taxifolia*	Black locust, *Robinia pseudoacacia*
Northern white cedar, *Thuja occidentalis*	Chestnut, *Castanea dentata*
Tamarack, *Larix laricina*	Red gum, *Liquidambar styraciflua*
Western red cedar, *Thuja plicata*	White oaks (except chestnut oak), *Quercus* spp.

* Not listed in original table.

is so resistant as to be practically impenetrable by commercial treating processes. In these species, the penetrations obtained on unincised heartwood faces are often not more than 1/16 in., although sometimes attaining a depth of 1/4 in.; the heartwood of the coast type of Douglas fir, southern yellow pine, and certain hardwoods, including hard maple, while moderately difficult to penetrate, can be impregnated to depths of 1/4 to 1/2 in. or more (8).

The generally greater permeability of sapwood over heartwood may be explained, at least in part, by anatomical, physical, or chemical alterations which take place as the sapwood changes to heartwood. This transformation is accompanied by the death of the living (parenchyma) cells of the sapwood and the resultant elaboration of resins, gums, tannins, etc., which give a definite color to the heartwood of many species and, when toxic, materially increase its natural durability. But these extraneous materials may also become hardened, especially in seasoned timber, and partially or completely plug up the cavities of vessels and resin ducts; in such cases, they materially decrease, if not entirely inhibit, the movement of preservatives through these natural openings. In the softwoods, resin may also be deposited in the bordered pits of the wood tracheids, clogging the minute perforations in the membranes and greatly impairing or completely destroying the permeability of these partitions to preservatives. Furthermore, there is usually a far more general aspiration of bordered pits in the heartwood than in the sapwood, and the displaced tori may be effectively sealed against the pit apertures by hardened resin.

In many hardwood species, the penetrability of the heartwood may be affected by the development of *tyloses*. These are pithlike outgrowths from ray or wood parenchyma cells, which gain entrance into the cavities of adjoining vessels through pits in their common walls of contact and then expand. They are often plainly visible, especially when abundantly developed in large vessels, and have a frothlike appearance, as a result of their high luster. They may develop in any part of the sapwood where water conduction is reduced but are usually produced in greatest abundance in the region that is being transformed into heartwood. (9, 25.)

In those woods in which they occur, tyloses may reduce the permeability of the vessels or even entirely close these channels to the passage of liquids. Furthermore, the occurrence of gums and other extraneous materials in association with tyloses will tend to make the closure of the vessels more nearly complete. Thus, in the heartwood of chestnut, black locust, and most of the white oaks, the vessels are so plugged with these intrusions that the passage of preservatives is completely obstructed; since the fibers and other elements are also resistant to impregnation, the heartwood of these species is almost impenetrable. In other woods, such as most of the red oaks and some of the ashes and elms, tyloses are rather sparsely developed and do not appear seriously to impede the penetration of the heartwood; the comparison between the white and red oak groups is especially significant, as the woods of these two groups have practically the same structure, aside from the variation in tylosal development.* In a number of hardwoods, including the maples, birches, and black and tupelo gums, tyloses are entirely lacking, although the vessels may be obstructed by gum. The fact that certain diffuse-porous woods, such as largetooth aspen, sycamore, and the maples, are inclined to receive more erratic penetrations than ring-porous timbers is possibly explained by the irregular distribution of tyloses or gums in their heartwood (23).

Similarly, the resin ducts in the heartwood of certain softwoods may be partially or completely closed by *tylosoids*, which differ from tyloses in that the surrounding wood parenchyma cells merely enlarge and do not pass through the cavities of pits. Such intrusions of the limiting layers of parenchyma cells into resin passages are of common occurrence in the pines but infrequent in the other softwoods that possess such ducts. Their effect on the penetrability of heartwood is comparable to that of the tyloses in the hardwoods.

DENSITY

The density (weight per unit volume, as pounds per cubic foot) of a normal piece of wood is determined very largely by the moisture content of the material and the amount of actual wood substance (cell walls) that it contains. Hence, when a timber is reasonably dry, its density indicates the approximate amount of air space (cell cavities) available to hold liquids. Water-soluble preservatives are taken into the cell walls during treatment to a far greater extent than creosotes and similar preservative oils, but it is recognized that, even with water solutions, the bulk of the absorbed preservative is located in the cell cavities. Consequently, the greater the volume of these cavities in seasoned wood (*i.e.*, the lower its density) the greater the absorption that should be obtained, if all the cavities are filled. However, owing to various obstacles to penetration, as well as to limitations in the length of treating periods, it is usually impossible to fill completely all of the available air spaces, particularly in timbers of structural size. What usually happens is that the outer shell of sapwood or penetrable heartwood in a timber is more or less saturated with preservative, while the inner core is less thoroughly treated, if it is impregnated at all.

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* Among the oaks, there are two conspicuous exceptions to the general rule of tylosal development in the heartwood. Blackjack oak, *Quercus marilandica*, while a member of the red oak group, is characterized by an abundance of tyloses; while chestnut oak, *Q. montana*, which belongs to the white oak group, has relatively few.

There is no general correlation between the density of wood and the penetration obtained, particularly in different species. As indicated in Table IX, heartwood of the relatively dense coast-type Douglas fir, longleaf pine, and mockernut hickory is more readily penetrated than that of such light-weight woods as western red cedar, corkbark fir, and chestnut; conversely, basswood and ponderosa pine are more easily penetrated than the appreciably heavier yellow birch and western larch. Furthermore, although their general density is approximately the same, tamarack is definitely more difficult to impregnate than shortleaf pine; lodgepole pine, than ponderosa pine; red gum, than black gum; and white oak, than red oak. In some cases, the reasons for this lack of correlation are obscure, but, in general, it may be accounted for by the recognized anatomical distinctions among the species concerned. Variations in the character and condition of the tracheid pits and resin ducts in the softwoods, and of the vessels and wood fibers in the hardwoods, are so much more significant than the density of the wood that any effect of this last factor is entirely obscured.

Within some individual species, however, the density of the wood may appear to be somewhat correlated with its penetrability. This is notably the case in certain softwoods, such as the southern pines, in which seasonal layers are clearly differentiated;

in these species, the relatively dense summer wood is more easily impregnated than the spring wood, with the result that both weight per unit volume and penetrability of a given piece of wood are directly influenced by the percentage of summer wood in the stick. On the other hand, an inverse relationship may be observed in most of the red oaks and certain other ring-porous hardwoods; in such species, pieces of low density (slow growth) usually have a higher proportion and more uniform distribution of large, open vessels than sticks of higher density (more rapid growth) and, consequently, may permit better penetration of preservatives.

DIRECTION OF PENETRATION

When timbers are impregnated with preservatives, definitely better penetrations are obtained from the ends (with the grain) than from the sides (across the grain) of the pieces. This is to be expected, in view of the structure of the wood. Unobstructed vessels and vertical resin ducts afford definite canals for the longitudinal passage of preservatives, while the axially elongated wood fibers and tracheids also facilitate movement in this direction. Except in those softwoods that possess unobstructed radial resin ducts, preservatives must pass through many cell walls in moving a relatively short distance across the grain (either radially or tangentially).

There is considerable difference of opinion as to the ratio of longitudinal to side penetration. One investigator (26) places this ratio at about 100 to 1 in heartwood and states that it may be even greater in sapwood, while another (16) gives a range of from 20 to 1 to as much as 128 to 1 for hardwoods and those softwoods that do not possess radial resin ducts. The latter authority states that, in those softwoods having radial ducts, the radial penetration is considerably greater than that obtained in the tangential direction, ranging from one-fourth to three-fourths as deep as the longitudinal penetration. A more precise estimate (Table X) has been made by MacLean (21), based on the average results obtained with five different woods subjected to various methods of treatment. In this study, it was determined that, except for the very refractory mountain-type Douglas fir, the longitudinal penetration ranged from about ten to twenty times as great as the side penetration when the wood was impregnated with creosote and from about fifteen to twenty-five times as great when zinc chloride was used. An average ratio of approximately 15 to 1 for preservative oils and 20 to 1 for water-soluble preservatives is suggested for general conditions.

TABLE X.—RATIO OF LONGITUDINAL TO SIDE PENETRATION OF PRESERVATIVES (21)

Species	General range of variation (ratio of longitudinal to side penetration)	
	Coal-tar creosote	Zinc chloride
Southern pine	5 to 18	7 to 25
Douglas fir (coast type)	15 to 22	15 to 33
Eastern hemlock	14 to 20	15 to 26
Yellow birch	12 to 18	15 to 20
Douglas fir (mountain type)	25 to 35	28 to 48

The structure of the wood also has a bearing on the relative depth of radial penetration (from the flat-sawed faces) and that obtained in the tangential direction (from the quarter-sawed surfaces). In some refractory softwoods, there appears to be little or no consistent difference between the movement of preservatives across the grain in the two directions; but in most coniferous species, the tangential penetration is usually superior, being facilitated by the continuity of the relatively permeable summer-wood bands and, possibly to some extent, by the predominance of pits in the radial walls of the spring-wood tracheids. Better penetration is obtained in the radial direction only in some of the softwoods having radial resin ducts and notably in certain of the pines. Among the hardwoods, the tangential penetration is generally considered to be superior.

In very short pieces of certain kinds of wood, such as southern pine paving blocks, it is possible to obtain thorough impregnation of the material by end penetration alone. But in the great majority of products, the pieces are so long that they cannot possibly be satisfactorily treated in this way, and penetration from the sides becomes the critical factor in determining the adequacy of the treatment obtained. In fact, pronounced end penetrations are actually undesirable in many forms of timber, since treatments beyond a certain depth from the ends are of no particular value in protecting the wood in service, and the excess preservative absorbed at such points is actually wasted. While penetration from the sides of a piece of wood is largely dependent upon the radial and tangential movement of the preservative, it is almost invariably assisted to some degree by a certain amount of longitudinal penetration. This results from the fact that the faces of sawed or hewed timbers are usually so cut, at least over localized areas, that the grain of the wood is not parallel to the sides of the sticks; consequently, the ends of many vessels (hardwoods) and tracheids (softwoods) are exposed and help conduct preservatives to varying depths beneath the surfaces. For this same reason, definitely cross-grained timbers can usually be penetrated to a greater depth than straight-grained pieces of the same kind of wood.

PREPARATION OF TIMBER

If satisfactory results are to be obtained in the treatment of wood, it is essential that the material be suitably prepared for the subsequent impregnation of preservatives. Timbers to be used in the round (poles, posts, mine props, and piles) and those that are sawed or hewed on two parallel faces only (pole ties) must be peeled to remove the impenetrable bark, while practically all of the commercial processes require that the wood be air seasoned or conditioned by such pretreatments as steaming and vacuum or boiling under vacuum. The practice of incising refractory woods, to insure uniformity and minimum depth of penetration (Fig. 66), is being extended, and the advantages of adzing, boring, and framing timber prior to treatment are now widely recognized. The details of these various steps in preparing material for treatment are discussed in Chap. V.

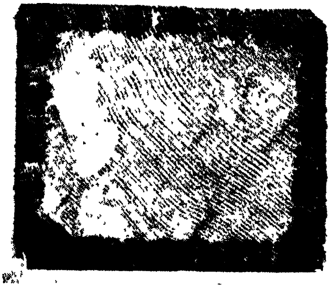

FIG. 66.—Uniform penetration obtained in an incised Douglas fir tie. (*A. T. and S. F. Ry.*)

Other than for incising, there are no precise data as to the effects of these several preparatory steps on the subsequent absorption and penetration of preservatives. Actual plant measurements of cedar poles disclosed the fact that western red cedar timbers, incised to a depth of ½ in. over the 3-ft. ground-line section, absorbed an average of 58 per cent more creosote than unincised poles of the same species, while in northern white cedar the absorption was 45 per cent greater in the incised timbers; furthermore, the extra preservative was concentrated in the ground-line section, thus adding material protection to this critical zone (13). Tests on matched Douglas fir beams showed that, whereas unincised sticks absorbed an average of 9.48 lb. of creosote per cubic foot, incised pieces absorbed 13.60 lb., or over 43 per cent more preservative, when treated under identical conditions (14). Incised Engelmann spruce ties, pressure treated with either coal-tar creosote or creosote-petroleum mixture for five or six hours, were found to have average side penetrations of ⅝ to ⅞ in. in the heartwood; under similar conditions, unincised heartwood faces had penetrations of but ¼ to ½ in. (22). This latter study further indicated that pressure periods shorter than those required for unincised ties could be used in treating the incised pieces.

FORM AND SIZE OF TIMBER

The form in which timber is treated may have a decided effect on the ease with which adequate penetration and absorption may be secured. Poles, piles, and other timbers used in the round, in which the heartwood is entirely incased in a layer of sapwood, are more readily impregnated than sawed or hewed products, such as crossties and construction timbers, in which the sapwood has been largely or entirely removed. Possible exceptions may be found in species having either refractory sapwood or readily penetrable heartwood. In ties and other sawed or hewed products, individual timbers commonly have both sapwood and heartwood faces, a condition that definitely complicates the problem of securing uniform penetrations and absorptions. In such cases, and particularly when the specified absorptions are relatively low, the preservative may be almost entirely taken up by the sapwood, thus affording little protection to the heartwood faces. While it is not possible to obtain equal penetration in the two types of wood, the inequality can be reduced by proper control of the treating procedure. The empty-cell processes are especially advantageous for the treatment of such material, since they make it possible to inject a great deal more preservative than is to be finally retained and in this way provide not only a thorough treatment of the sapwood but also a definite penetration in the more resistant heartwood.

Another factor, not always appreciated, is that the absorptions specified for given treatments should bear some relation to the dimensions of the timbers to be impregnated (21, 23). All too often, this fact is not taken into consideration, and the absorptions specified are merely those currently used for crossties; they may have distinct limitations when applied indiscriminately to the great variety of timbers, of widely different dimensions, that are subjected to treatment today. If all of the wood could be thoroughly penetrated, absorptions based on the volume of the timber would give comparable treatments regardless of the sizes of the pieces involved. However, very few species can be completely impregnated in the heartwood, even in relatively small sticks, and considerable variation in depth of penetration usually results when timbers of different lengths and cross-sectional dimensions receive the same net retention of preservative per cubic foot.

These discrepancies in treatment are due to variations in the ratio of surface area to volume in timbers of different size. Some wood users consider an absorption of 8 lb. of creosote per cubic foot of wood sufficient for poles to be used under ordinary service conditions, since the preservative will be distributed through a shell of treated wood sufficiently thick to provide good protection. In inch lumber, however, this absorption is too low for good penetration, since the surface area of a cubic foot of such material is very large, and the preservative must spread out rather thinly to cover it. On the other hand, such an absorption may be too high for extremely large bridge timbers of resistant heartwood, as it may be impossible to force that amount of preservative into the wood under normal treating conditions. The necessity for considering the dimensions of various wood products is recognized in government treating specifications and in those of some state highway departments, different minimum absorptions being stipulated for different sizes of timber and conditions of service.

MacLean (23) illustrates the need for considering the sizes of timbers to be treated, by comparing a 7- by 9-in. by 8-ft. heartwood crosstie with the same timber cut into four pieces, each 3½ by 4½ in. by 8 ft. in size. The total volume of wood is approximately 3½ cu.ft. in both cases, but there is a decided difference in the surface areas involved. The tie has a total surface area of about 22.2 sq. ft., while that of the four pieces is 43.54 sq. ft., or approximately 96 per cent more. It is evident that a given absorption, such as 28 lb. of creosote (8 lb. per cubic foot of wood), will penetrate farther when injected into the tie than when spread over the much larger surface area of the four pieces.

The data presented in Table XI indicate the approximate amount by which the volumetric absorptions in various sizes of heartwood timbers, or timbers containing only a small amount of sapwood, should be increased or decreased to give a treatment equivalent to that obtained in a 7- by 9-in. by 8-ft. stick (21). This specified timber, of crosstie size, is taken as the standard for comparison, because the necessary volumetric absorptions for material of that size have been fairly well determined through extensive treating experience. The data apply to any given absorption and to treatments by either full-cell or empty-cell processes.

GROUPING MATERIAL FOR TREATMENT

The foregoing discussion of the factors affecting the absorption and penetration of preservatives has clearly indicated the desirability of including in a given treating charge only those timbers that have approximately the same susceptibility to impregnation. Otherwise, the more readily impregnated pieces will tend to receive appreciably more, and the more refractory sticks definitely less, than the average amount of preservative specified per cubic foot of wood in the charge.

In such products as poles and piles, suitable uniformity of treatment is usually less difficult to obtain than in sawed material, since the timbers are generally of but one kind of wood, round in form and hence completely inclosed with a layer of sapwood, of comparable degree of seasoning, and fairly uniform in size. Nevertheless, even in these timbers there may be marked differences in absorption and penetration in apparently similar sticks treated in the same charge. With certain other products, such as crossties, there is often greater need for grouping the pieces prior to treatment. A number of different species of wood may

TABLE XI.—PERCENTAGE VARIATIONS IN ABSORPTION REQUIRED IN HEARTWOOD TIMBERS OF DIFFERENT SIZES (21, 23)

(Based on results obtained with 7- by 9-in. by 8-ft. timbers. See text for explanation.)

Size of timber		Increase or decrease in absorption		Size of timber		Increase or decrease in absorption	
Nominal cross section, inches	Length, feet	For preservative oils,* per cent	For water solutions,† per cent	Nominal cross section, inches	Length, feet	For preservative oils,* per cent	For water solutions,† per cent
2 by 4	All lengths‡	+74	+56	8 by 8	4	+33	+40
2 by 6	All lengths‡	+64	+48		8	− 1	0
2 by 8	All lengths‡	+58	+42		12	−12	−14
2 by 12	All lengths‡	+51	+36		16	−18	−21
3 by 6	4	+73	+70	8 by 12	4	+26	+34
	8	+49	+41		8	−10	− 8
	12	+41	+32		12	−21	−22
	16	+37	+27		16	−27	−29
3 by 10	4	+65	+64	8 by 16	4	+22	+32
	8	+38	+33		8	−14	−12
	12	+30	+22		12	−26	−26
	16	+25	+17		16	−32	−33
4 by 4	4	+72	+70	10 by 12	4	+21	+31
	8	+47	+40		8	−15	−12
	12	+39	+30		12	−27	−27
	16	+35	+25		16	−33	−34
4 by 8	4	+54	+56	10 by 16	4	+18	+28
	8	+26	+21		8	−19	−16
	12	+16	+10		12	−32	−31
	16	+11	+ 4		16	−38	−38
4 by 12	4	+48	+51	12 by 14	4	+16	+27
	8	+18	+15		8	−21	−18
	12	+ 8	+ 3		12	−34	−33
	16	+ 3	− 3		16	−40	−40
6 by 8	4	+40	+45	14 by 14	4	+14	+25
	8	+ 8	+ 7		8	−24	−20
	12	− 3	− 6		12	−36	−35
	16	− 8	−12		16	−42	−43
6 by 12	4	+33	+40	16 by 16	4	+11	+23
	8	0	0		8	−28	−23
	12	−12	−14		12	−40	−39
	16	−17	−20		16	−47	−46
6 by 16	4	+30	+37				
	8	− 5	− 4				
	12	−16	−18				
	16	−22	−24				

* Unit end absorption assumed to be fifteen times unit side absorption.

† Unit end absorption assumed to be twenty times unit side absorption.

‡ End absorption in timbers 2 in. thick is negligible.

be involved; the proportion of sapwood to heartwood may vary considerably in different pieces, and there may be definite variations in the moisture content of the individual timbers. In certain classes of wood products, such as miscellaneous lumber and construction material, mixed sizes may also have to be considered.

Whenever possible, different sizes of timber should be treated separately. However, it very often happens that the amount of mixed-dimension material to be impregnated is too small to make such a procedure feasible. In such cases, the different sizes can be treated together, provided that the necessary absorption is correctly estimated. This can be done by multiplying the volume of the timber in each size class by the unit absorption that should be injected for that particular class (Table XI) and adding the amounts thus obtained for all of the sizes involved.* When this indicated quantity of preservative is injected into a charge of heartwood (or mostly heartwood) timber, the wood in the several size classes will absorb amounts more or less in proportion to their surface area-volume ratio. This method of calculating absorption for mixed sizes will not apply, however, if the material in the charge varies appreciably in its susceptibility to treatment.

TREATING PROCEDURE

The adequacy of the treatment received by a given timber or group of timbers is dependent upon the treating procedure fully as much as upon the anatomical characteristics of the wood and the condition of the material. The general nature of the process used has considerable significance in determining the amount of preservative absorbed and the depth to which it penetrates; but such individual treating variables as the character and viscosity of the preservative, the degree of temperature and amount of pressure used, and the length of the treating period are also important.

Type of Process

Deep penetrations and suitable absorptions can be obtained in thoroughly green wood by using strong solutions of water-soluble preservatives and time-consuming diffusion methods or by means of the Boucherie type of treatment. Otherwise, it is only in exceptional cases that a nonpressure treatment gives absorptions and penetrations comparable to pressure methods, in either green or seasoned material. For timbers to be used under conditions involving mechanical wear (crossties) or severe exposure to agencies of deterioration (marine piling), nonpressure methods are particularly inadequate. In the great majority of cases, the pressure processes not only provide greater protection to the wood in service but are also definitely more economical in the long run.

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* An example of the application of this rule is given on page 85 of reference (23).

The type of pressure treatment chosen also has a marked influence on penetration, for, as explained in Chap. VI, empty-cell processes give much better penetration, with limited absorptions, than the full-cell method. In thoroughly air-dry and easily treated wood, the amount of preservative finally retained in an empty-cell treatment may be as little as 40 per cent of the gross absorption; but in green or partially seasoned timber or in dry wood that is difficult to impregnate, it will be appreciably more.

CHARACTER OF PRESERVATIVE

It is a matter of general observation that the kind of preservative used may have a pronounced effect on the ease and thoroughness with which wood can be impregnated. Under similar conditions of treatment, better penetrations and absorptions are usually obtained with water-soluble salts than with preservative oils (20, 22, 23), while straight creosote generally gives better results than creosote mixtures (18, 32). Furthermore, in the case of the creosote mixtures, resistance to penetration has been found to increase as the proportion of coal tar or petroleum oil is increased. Thus, eastern hemlock ties treated with a mixture containing equal proportions of creosote and petroleum oil absorbed about 10 per cent less preservative than those impregnated with straight creosote under the same treating conditions; when the proportion of petroleum was increased to 90 per cent, the absorption was about 25 per cent below that in the creosoted ties (18). The relative depth of penetration decreased to approximately the same extent as the absorption in each case. In these investigations of creosote mixtures, it was also found that the particular kind of tar or petroleum used had a definite influence on the facility with which the preservative was taken up by the wood.

The diversity in absorption and penetration obtained with various types of preservative may be largely accounted for by differences in the viscosity of the liquids (4, 17–19, 23), although the fact that water solutions are taken up by cell walls to a much greater extent than preservative oils may also help to explain the superior penetrations obtained with zinc chloride and other water-soluble preservatives. The distinctive differences in viscosity between zinc chloride solution, coal-tar creosote, petroleum, and the two different mixtures of creosote and petroleum cited in the preceding paragraph are clearly shown in Fig. 67. It is apparent that the viscosity of creosote mixtures can be varied over wide limits, depending upon the viscosity of the particular coal tar or petroleum used and the amount of such material in the mixture.

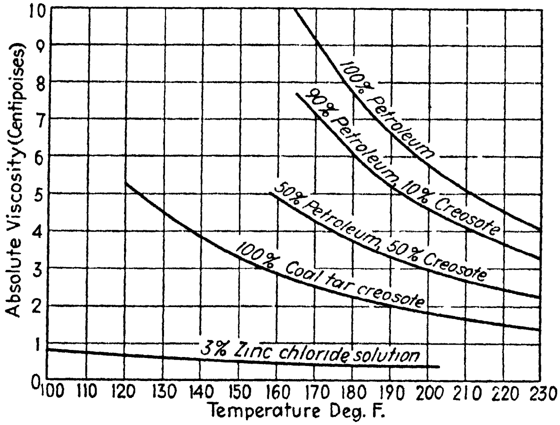

FIG. 67.—Viscosity-temperature relations of zinc chloride solution, coal-tar creosote, creosote-petroleum solution, and petroleum. (*U.S. Forest Products Laboratory.*)

VISCOSITY AND TEMPERATURE

It will be noted in Fig. 67 that the viscosity of a given preservative is very definitely influenced by its temperature. This is particularly outstanding in the case of the preservative oils, which have high viscosity at ordinary room temperatures but become increasingly thinner and more fluid, and consequently penetrate wood more readily, as they are heated. However, even the relatively small decrease in viscosity of zinc chloride solution that takes place as the temperature increases is known to produce a definite improvement in penetration and absorption (17, 20, 22, 23). Data in support of this contention are presented in Table XII, which shows the average penetrations and absorptions of a 3 per cent solution of zinc chloride obtained in air-seasoned yellow birch and eastern hemlock ties. The treat-

TABLE XII.—RELATION OF TEMPERATURE TO PENETRATION AND ABSORPTION IN ZINC-CHLORIDE-TREATED BIRCH AND HEMLOCK TIES (23)

Species	Pressure period, hours	Preservative temperature, degrees Fahrenheit	Absolute viscosity, centipoises	Average side penetration (heartwood), inches	Average absorption per square foot of surface, pounds	
					Net	Gross
Yellow birch	4	140	0.54	0.32	3.0	3.1
	4	160	0.46	0.38	2.9	3.1
	4	180	0.39	0.55	3.1	3.3
	4	200	0.34	0.75	3.2	3.5
Eastern hemlock	4	160	0.46	0.53	2.8	3.0
	4	180	0.39	0.69	3.0	3.4
	4	200	0.34	0.88	3.3	4.1
	5	160	0.46	0.71	2.7	2.9
	5	200	0.34	0.84	2.7	3.7

TABLE XIII.—RELATION OF TEMPERATURE TO PENETRATION AND ABSORPTION IN CREOSOTED EASTERN HEMLOCK TIES (23)

Preservative temperature, degrees Fahrenheit	Absolute viscosity, centipoises	Average side penetration, inches	Average absorption per square foot of surface, pounds	
			Net	Gross
140	3.80	0.29	1.36	1.43
160	2.81	0.39	1.78	1.89
180	2.22	0.45	2.01	2.15
200	1.80	0.51	2.27	2.54
220	1.50	0.61	2.58	3.18
240	1.22	0.67	2.61	3.85

ment of this material involved a 30-min. preliminary vacuum (about 28 in.) and a pressure of 150 lb. for the indicated periods; no final vacuum was used.

Studies of creosote treatments (4, 18–20, 22, 23) have shown conclusively that an increase in preservative temperature improves penetration, and usually both net and gross absorption, other factors being constant. Table XIII is presented to show the actual results obtained in air-seasoned eastern hemlock crossties, treated with coal-tar creosote by the full-cell process. The penetrations and net and gross absorptions indicated for the specified temperatures were averaged for the pressures of 125, 150, and 175 lb. per square inch used in the investigation and are based on the treatment of from 72 to 75 ties in each case.* The depth of penetration was also found to increase at higher temperatures in treatments with mixtures of coal-tar creosote and petroleum oils, although the increases in absorption were not so consistent, and neither the penetrations nor the absorptions approached those that were secured when the less viscous straight creosote was used (18). Similar results were obtained when wood was impregnated with mixtures of creosote and coal tar (32).

While the improvement in penetration and absorption brought about by increased temperature is chiefly the result of the lowered viscosity of the preservative, there is reason to believe that conditions are also made more favorable for impregnation by the increased heating of the wood itself. Evidence to support this claim is found in the data (18, 19, 23) obtained from treatments in which the temperatures of the various preservative oils used were so regulated as to give comparable absolute viscosities. The somewhat greater absorptions and penetrations obtained with the hotter preservatives indicate that temperature itself is a factor of some importance in the treatment of wood.

The depth to which heat penetrates a timber may be a significant factor in its treatment, because of the effect that the cooler interior portions may have in lowering the temperature of the preservative as it penetrates the wood. This is particularly true

* It will be noted, in comparing Tables XII and XIII, that the zinc chloride treatments gave somewhat higher absorptions, in proportion to the penetrations obtained in eastern hemlock ties, than did the creosote treatments. MacLean (23) suggests that this is probably the result of the deeper end penetration that is secured with water-soluble preservatives, as well as the marked absorption of the water solution by the cell walls of the wood.

in the case of timbers that are naturally resistant to impregnation. The extent of heat penetration in a given timber during treatment is dependent upon a number of variables, including the original temperature of the wood, the temperature of the preservative, the heat conductivity of the wood, the size and penetrability of the piece, and the length of the heating period (23). Except in very small sticks, the heating periods used in commercial practice are usually too brief to raise the temperature at the center of the wood to a favorable treating point. This is the case not only with air-seasoned timber but also with wood that has been conditioned by steaming and vacuum or boiling under vacuum.

The temperatures that have been most commonly used in pressure treating wood ranged from about 160 to 185°F. But with heartwood in general, and the more resistant species in particular, it has been shown that temperatures of 190 to 200°F. are much more favorable, for both water-soluble salts and preservative oils, and treating plants are using these temperatures more frequently. In combination with relatively high pressures, these higher temperatures may cause more or less collapse, checking, or distortion in refractory woods, but these defects may be avoided if the temperatures are maintained and the pressures reduced. More satisfactory impregnations are secured when this procedure is followed than when the temperatures are lowered (22, 23).

There are some special instances in which high temperatures are to be avoided. Such is the case with certain water-soluble proprietary preservatives which, when heated above a given point, are precipitated from the solution before entering the wood. Partial precipitation may occur from solutions of chromated zinc chloride and Wolman salts at high temperatures; hence it is common practice not to exceed about 150°F. with these preservatives. Resin tends to accumulate on the surface of resinous softwoods treated with water solutions at high temperatures. Since this is very undesirable when painting is required, it militates against the use of high temperatures with such material.

PRESSURE

The amount of pressure used and the period of time over which it is applied are both significant factors in the impregnation of wood, although within the commercial treating ranges they are not considered to be so important as the temperature of the preservative. Such experimental data as are available (17, 19, 20, 23) indicate that, as each (or both) of these pressure variables is increased, the resultant penetration and absorption are likewise increased. The results obtained in impregnating air-seasoned, sawed, mountain-type Douglas fir crossties with a 3 per cent solution of zinc chloride are presented in Table XIV. In this investigation, the solution temperature was kept relatively low (175°F.), so that a wide range of pressures could be used. Although restricted to zinc chloride, the tabulated data are also indicative of the general results obtained with preservative oils. Investigations have also shown that the effect of a given increase in treating pressure is appreciably greater at high preservative temperatures than at low. Thus, in creosoting eastern hemlock ties, the increase in depth of penetration

TABLE XIV.—RELATION OF INTENSITY AND DURATION OF PRESSURE TO PENETRATION AND ABSORPTION IN ZINC-CHLORIDE-TREATED MOUNTAIN-TYPE DOUGLAS FIR TIES (20)

Treating pressure, pounds per square inch	Treating period, hours	Average absorption, pounds per cubic foot of wood		Average penetration, inches	
		Net	Gross	Side	End
100	2	5.5	5.9	0.20	6.8
	4	7.8	8.1	0.20	8.8
	6	10.2	10.7	0.29	13.0
	8	11.5	12.0	0.32	15.9
150	2	8.4	9.0	0.25	10.5
	4	9.6	10.4	0.25	9.4
	6	14.2	15.5	0.27	16.1
	8	15.0	17.1	0.38	18.2
200	2	9.1	11.5	0.25	9.8
	4	11.5	15.7	0.31	16.9
	6	13.5	17.4	0.39	17.0
250	2	8.9	14.1	0.20	13.4
	4	13.3	23.5	0.34	19.4
	6	16.0	27.2	0.41	30.0

accompanying a change in pressure from 125 to 175 lb. was found to be about 70 per cent greater at 200 than at 140°F. (19). In Douglas fir, the increased penetration of zinc chloride accompanying this same rise in pressure was approximately 60 per cent greater at 200 than at 160°F. (17).

The combination of intensity and duration of pressure that will be best suited for a given treatment of wood is difficult to determine accurately, since it is dependent upon a variety of factors, including the absorption desired, the facility with which the timber can be impregnated, and the temperature of the preservative. In actual commercial practice, it varies over wide limits, being based largely upon the experience gained in previous treatments of the same species and type of material. As a general rule, it may be said that the treating period should be as long as practicable, and the intensity of pressure so regulated as to insure the desired absorption. Investigations have shown that moderate pressures and reasonably long periods of impregnation give better results than very high pressures and short treating periods. The penetrations obtained under the latter conditions are very apt to be erratic, and the absorptions may also be unsatisfactory. However, there is little or nothing to be gained by maintaining the pressure after the absorption of preservative has practically ceased.

The use of a prolonged treating period is particularly significant in impregnating refractory timbers, since the long pressure period permits more thorough heating of the wood and thus facilitates the movement of the preservative. The advantages of such a procedure are indicated by the data presented in Table XIV, which show that 6- and 8-hr. zinc chloride treatments of mountain-type Douglas fir were definitely superior to those lasting but 2 or 4 hr.; furthermore, an increase of 2 hr. in the treating period (intensity of pressure constant) improved the penetrations and absorptions more than a 50-lb. increase in pressure (treating period constant). The bearing of the temperature of the wood on its rate of absorption of preservatives may also be reflected in the length of the pressure period needed to inject a stated amount of preservative into timber that has been conditioned for treatment in different ways. Thus, in treating Douglas fir, shorter pressure periods are generally used to obtain the specified absorption in timber conditioned by boiling under vacuum, and hence having a relatively high initial temperature, than in air-seasoned wood. Likewise, air-seasoned timber treated during the winter months generally requires longer pressure periods than similar material that is impregnated during the summer. Recognizing the value of high initial wood temperatures, a few plants have adopted the practice of preheating resistant species by allowing them to stand in hot preservative (creosote) for some time before pressure is applied. There is reason to believe, however, that better results would be obtained over the same total period of treatment if pressure were applied at the start (23).

Commercial treatments also vary with regard to the rate at which the treating pressure is increased. At some plants, the practice is to apply the maximum pressure as soon as it can be attained, while at others the pressure is raised gradually, sometimes requiring as much as 2 hr. to reach the maximum. In the latter cases, the average pressure maintained over the treating period is definitely less than the maximum. There appears to be no inherent disadvantage in approaching the maximum quickly, if it is low enough to make the pressure period of reasonable length; very high pressures and very short impregnation periods favor erratic penetration. Gradual application of pressure avoids reaching the specified absorption too quickly and, in fact, often makes it unnecessary to use the permissible maximum.

The limit to which pressure may be raised, without causing the wood to check or collapse, varies considerably with different species, being obviously dependent, at least to some degree, upon the mechanical strength of the wood. It is also related to the size of the timber, apparently being higher for large pieces than for small ones (17). Furthermore, air-seasoned wood may be safely subjected to higher pressures than green timbers or those that have been heated for a long time (23); this is undoubtedly due to the greater plasticity of the wet and hot wood, which makes it more susceptible to distortion under pressure. The length of the pressure period must also be considered in this connection, but trouble can best be avoided in timbers that are susceptible to collapse and checking by lowering the pressure and prolonging the period of treatment until the desired absorption is obtained.

While mountain-type Douglas fir offers more resistance to penetration than coast-type fir, it nevertheless appears to withstand high pressures better than the latter. In treating coast-type fir timbers of crosstie size with a 3 per cent solution of zinc chloride, 175 lb. is recommended as a maximum safe pressure, when the preservative temperature is to be maintained at 175°F. (17); on the other hand, mountain-type fir ties showed no evident injury at that same temperature when subjected to 200 lb. pressure for 6 hr. or even 250 lb. for 2 hr. (20). Considerable collapse was found in small-sized specimens of coast-type Douglas fir, treated for 3 hr. with zinc chloride solution at a temperature of 200°F. or over and pressures of 150 and 175 lb.; in heart long-leaf pine specimens of the same size, treated for the same period at 175 lb. and 212°F., the injury from collapse was practically negligible (17). Because of its low mechanical strength, cork-bark fir developed severe collapse when treated with either creosote or zinc chloride at pressures in excess of 125 lb. per square inch (20).

In actual commercial practice, the pressures used in the full-cell and Lowry treatments vary from about 100 to 200 lb. per square inch, depending largely upon the ease with which the wood can be impregnated, but are generally within the range of 150 to 175 lb. In the Rueping process, they are usually between 150 and 200 lb., being influenced by the preliminary air pressure as well as the character of the timber.

INITIAL, GROSS, AND NET ABSORPTION

During a complete treating cycle, involving not only the actual pressure period but also such preliminary and final treatments (air pressure and vacuum) as are given, several rather definite stages of absorption (and subsequent partial evacuation) of preservative are recognized. These are known as the initial, gross, and net absorptions, being attained in the order named.

Initial absorption is the term used to designate the quantity of preservative that is taken up by the wood prior to the recognized pressure period. Specifically, it refers to the oil or water solution that enters air-seasoned or steamed timber while the cylinder is being filled with preservative or that is absorbed by the wood during the boiling-under-vacuum (Boulton) treatment. The amount of such absorption is quite variable in different treating charges, since it depends upon the kind and condition of the particular timber involved and the preliminary treatment (air or vacuum) that it has received as well as upon other possible treating conditions. The initial absorption of oils and water-soluble preservatives, measured in full-cell treatments of seasoned hemlock crossties, ranged from 1½ to 3 (average 2) lb. per cubic foot of wood; that in red oak ties varied from 3½ to 6 (average 4) lb. (23).

The total amount of preservative that has entered the wood by the end of the pressure period is known as the *gross absorption*. This includes both the initial absorption and the quantity of preservative that has been injected as a direct result of the applied pressure. The wood may often be compressed, as the result of the pressure of the surrounding liquid, thus making room in the cylinder for additional preservative. This introduces an element of error in the gauge or scale reading of the gross absorption, since the extra liquid does not actually enter the wood. When the pressure is released, some of the preservative that went to make up the gross absorption will be forced out of the wood, as a result of the expansion of the air that was compressed in the timber. Wood that was compressed during the pressure period may also expand to its original volume, thus forcing additional preservative out of the cylinder. Augmenting the *kickback* from these two sources, especially in the empty-cell processes, is the added amount of preservative that may be recovered when the wood is subjected to a final vacuum. The amount of preservative retained in the wood after the completion of the entire treating cycle is referred to as the *net absorption*, or *net retention*. Thus, the net absorption represents the difference between the gross absorption and the sum of the kickback and the preservative recovered during the final vacuum.

The total amount of preservative recovered after pressure is released is much greater in an empty-cell than in a full-cell treatment. For example, it commonly varies from about 25 to 60 per cent of the gross absorption in southern pine poles treated by an empty-cell process, while in similar material impregnated by a full-cell treatment it is generally appreciably less than 25 per cent. This is largely the result of the much greater amount of air that is imprisoned and compressed in the wood during the former type of treatment. The final vacuum is an important step in the empty-cell processes, since it facilitates the expansion of the trapped air and thus speeds up the recovery of the preservative; it is generally maintained only long enough to prevent any pronounced loss of preservative, through dripping, after the treated material has been removed from the cylinder. When used in the full-cell process, the chief purpose of the final vacuum is to leave the surface of the wood in a relatively dry and clean condition.

The expulsion of a significant amount of preservative in the empty-cell treatments makes it possible to obtain fairly large gross absorptions and deep penetrations with relatively small net absorptions. With any given gross absorption, however, the net retention may vary over wide limits, depending upon the character of the wood and the conditions of treatment. For this reason, gross absorption is considered to be a definitely better indicator of depth of penetration than net absorption.

The natural resistance of wood to impregnation, as determined by such factors as the species, relative amount of heartwood and sapwood, and moisture content, has a definite effect on the amount of preservative recovered, regardless of the type of process used. In full-cell treatments of air-seasoned sapwood ties of various species, the quantity of preservative oil recovered was found to constitute from 4 to 10 per cent of the gross absorption, while in similar treatments of resistant heartwood ties it amounted to about 6 to 25 per cent; when zinc chloride solution was used, the recovery was somewhat greater than with the preservative oils (23). Among the factors of treatment that may exert a definite influence upon the recovery of preservative, and particularly upon the kickback, are such variables as the temperature of preservative, the duration of treating period, the intensity of the pressure used, and the extent to which the wood is compressed (17, 20, 23). The effect of the first three of these factors is indicated in Tables XII, XIII, and XIV, which show that, as each variable is increased, the difference between the gross and net absorptions is also increased; the effect of the higher pressures is particularly significant, probably in large part because of its influence on the compression of the wood.

DETERMINATION OF ABSORPTION AND PENETRATION

In actual plant practice, the net absorptions of preservatives are usually determined from recorded measurements of the amount of preservative present in the working tanks before and after treatment. In most cases, these measurements are based on gauge readings, which indicate the *volume* (number of gallons or tank feet) of preservative taken in by the wood; but in some plants, the tanks are mounted on scales, and the *weight* (number of pounds) of preservative absorbed by a given charge is obtained. In the former case, the determined volume may be reduced to a weight basis by multiplying it by the weight per unit volume of the particular preservative concerned. Since the weight of a unit volume of a given preservative varies with the temperature, it is necessary to take temperature into consideration in converting volumes to weights. Specification 13c of the American Wood-Preservers' Association (1) gives conversion factors for creosote, coal tar, and creosote-coal-tar solution, over a wide range of temperatures. Such conversions are not necessary, of course, when the absorption is determined by means of tank scales.

The net absorption in pounds per cubic foot is determined by dividing the recorded weight of preservative by the volume of the wood in the charge. At some plants, the absorption is expressed on the basis of the average number of gallons of preservative retained per tie or other product of a given size. In the case of water-soluble preservatives, the equivalent amount of dry salt in the wood will depend upon both the net absorption and the strength of the solution used.

The net absorption of preservative may be determined, under certain conditions, by weighing the timber on track scales, located outside the cylinder, both before and after it is treated. In some plants, such a procedure is followed for inspection purposes, as a check on one of the other methods. Although some of the volatile parts of creosote evaporate from hot wood immediately after a charge is removed from the treating cylinder, the weights of the wood afford a fairly dependable means of measuring absorption in thoroughly air-seasoned timber. With green or partially seasoned wood, however, weighing the charge before and after treatment may indicate absorptions considerably lower than those actually obtained, since there are opportunities for unmeasured moisture changes in such wood at several stages during the processing. For example, green wood conditioned by the steaming-and-vacuum or boiling-under-vacuum methods loses weight as a result of the conditioning, and, unless the amount of such loss is determined and corrected for, the charge weights will give a false indication of preservative absorption. There is also some loss of moisture from green or partially seasoned wood during the final vacuum period, and this must be taken into consideration. Finally, when a hot charge of moisture-laden wood is removed from the treating cylinder, the loss of moisture during the first few minutes may be so rapid that weights cannot be taken quickly enough to avoid considerable error.

After a charge of timber has been treated, it is not possible to determine, either by inspection or by analysis, whether the specified amount of preservative has been retained in the wood. This is due to the fact that the nonuniform distribution of preservative throughout the length of the pieces makes it impracticable to obtain a correct average sample of the impregnated timber, without destroying most of it. Consequently, the purchaser of treated wood must either accept the statements or affidavit of the treating plant operator, or have an inspector at the plant to observe the treatments and insure compliance with the specifications.

Measurements of penetration, on the other hand, may be made at any time after the wood is impregnated, although, when professional inspection service is provided, they should, for convenience, be made at the treating plant. When such inspection service is not available, these measurements may be the purchaser's only criteria of the thoroughness of treatment. Rejection of treated timber, because of insufficient penetration, may be difficult to enforce, however, unless this point is definitely covered in the specifications, or there is previous agreement with the plant on minimum and average penetration requirements.

SPECIFICATIONS OF ABSORPTION AND PENETRATION

The absorptions specified by purchasers or users of treated wood vary considerably, according to the conditions under which the material is to be used and also because of often marked differences of opinion as to what constitutes adequate protection for a particular type of service. With zinc chloride, the standard practice for many years was to require net absorptions of ½ lb. of dry salt per cubic foot of wood, but more recently the tendency has been to favor retentions of ¾ to 1 lb., especially in lumber and small-dimension material. The heavier absorptions provide distinctly better treatments. With proprietary water-soluble preservatives, absorptions of about ¼ to ⅓ lb. per cubic foot are usually specified, but the adequacy of such low absorptions remains to be proved.

In creosoting timber for land use, net absorptions of 6 to 12 lb. per cubic foot of wood are commonly used for ties, and 8 to 12 lb. for lumber and timbers, the precise amount of oil being varied for different species, proportions of sapwood, and conditions of use. These absorptions should be increased for small-dimension material, while they may need to be reduced for very large heartwood timbers. The full-cell process was formerly used to a very large extent for securing absorptions of 10 to 16 lb., but it is now standard practice to employ an empty-cell treatment whenever the desired absorption can be obtained by that method. Piles, to be used in salt water where marine borers are active, should be creosoted by the full-cell process to virtual refusal; this may mean absorptions of 20 to 25 lb. per cubic foot in southern pine and 12 to 18 lb. in Douglas fir. The highest absorptions can be obtained only in sapwood timber that has been thoroughly air seasoned.

In many cases, it may be desirable to specify the minimum and average penetrations that will be acceptable to the purchaser. However, care must be taken to see that the imposed requirements are practicable in the sizes of timber involved and with the absorption and methods of treatment called for. At the present writing, revision of the treating specifications of the American Wood-Preservers' Association is being made, with the objective of improving the penetration requirements. When completed, these revised requirements should afford a good indication of the penetrations that can be readily furnished.

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CHAPTER VIII

ECONOMIC ASPECTS OF PRESERVATIVE TREATMENT

Of the various factors that should be analyzed before choosing a specific kind of construction material for use in building a bridge, wharf, pole line, railway track, or other structure, economy is usually regarded as most important. Obviously the material should be sufficiently strong to support the loads that may be placed upon it, and otherwise physically adapted for the particular purpose for which it is to be used. In some types of construction, major consideration may be given to fire resistance or other special requirements; and in certain monumental structures, appearance may be stressed more than financial considerations. But when several different materials are capable of performing the required service, as is generally the case, the final selection is usually made on the basis of the costs involved.

For a given structural use, the choice among wood, steel, and concrete, or between treated and untreated timber, is often made on the basis of the initial costs of these materials, including the estimated charges for installation. However, while low *first cost* (*in place*) is much sought after and may be the prime requirement for temporary structures, the real criterion of economy in permanent forms of construction is the ultimate cost of the materials used. Since this is determined by the *annual charge* imposed against entire structures, such as railway tracks or wharves, or against individual construction items, such as crossties or piles, from the time of their completion or installation to their retirement, it necessarily involves consideration of the *serviceable life* of the materials. In viewing the expense of complete structures, the serviceable life of individual members is also reflected in the *cost of maintenance*, but this economic factor, like those of possible *obsolescence* and *salvage value*, may be difficult to forecast.

FIRST COST, IN PLACE

The estimated first cost of any structural item (or completed structure) must include all expenses incidental to putting it into actual service, if accurate comparisons are to be made among the various construction materials. Installation charges, alone, may vary within wide limits, depending upon the type of construction and the particular kind of material used, and, in some cases, they may definitely exceed the cost of the structural items delivered to the job. For example, the expense of installing a pole in a high-voltage transmission system or in a city distribution line may be as high as from $50 to $150, while the delivered cost of the structural member itself may be only $20 to $30.

The first cost, in place, of most treated wood products (and timber structures) is generally conceded to be considerably less than that of similar items made of steel or concrete. Consequently, the use of treated wood often makes it possible to carry out a given building program at less expense, or to erect more structures for a given sum of money, than when more costly construction materials are employed. This economic advantage of treated timber may be illustrated by considering the present nation-wide highway problem of eliminating grade crossings.

The Committee on Grade Crossings of the American Road Builders' Association, in 1929, reported on the design and estimated cost of several types of overpass structures for use over single and double railway tracks (6) and submitted the comparative data on trestles of creosoted timber and other materials incorporated in Table XV. In considering the different materials of construction, the most economical design was selected for each type. The committee pointed out, for example, that the simply

Table XV.—Estimated Costs of Highway Overpass Structures Constructed of Different Materials

Type of structure	Total cost	Ratio of cost	Length, feet	Cost per linear foot
For one track:				
Creosoted timber	$ 4,469.08	1.00	79	$ 56.57
Steel	8,073.14	1.81	78	103.50
Concrete	10,206.24	2.28	83	122.97
For two tracks:				
Creosoted timber	6,841.67	1.00	94	72.78
Steel	8,845.69	1.29	91	97.21
Concrete	11,052.38	1.62	96	115.13

supported type of construction ordinarily used for concrete overhead structures would cost about 25 per cent more than the recommended rigid design.

On the basis of the estimates given in Table XV, steel structures would cost 81 per cent more over single railway track and 29 per cent more over double track than overpasses made of creosoted timber. Overhead structures built of reinforced concrete would be still more expensive, costing 128 per cent more over single track and 62 per cent more over double track than those constructed of treated wood.

The economies effected through the use of treated timber for highway bridges are further exemplified by the actual experience of two different state highway departments. The state of Wyoming, by building bridges of creosoted timber wherever such material was suitable, instead of using the more expensive concrete or steel formerly required, was able to save more than a million dollars over a period of about 5 years and to apply this sum to additional road construction (22). It was found that the timber bridges could be constructed at about one-third the cost of steel and concrete structures, resulting in an average saving of $120 per linear foot (20). Similarly, the state of Nebraska by building 93 creosoted highway bridges made an aggregate saving of $375,000, or an amount sufficient to gravel more than 150 miles of road, during a period of 4 years (7). The total length of these 93 structures was 6236 ft., so that the reduction in cost was in excess of $310,000 per mile of bridge.

The first cost of treated timber naturally exceeds that of otherwise comparable untreated wood. In some instances, particularly those requiring the use of relatively cheap products and low installation charges, the expense involved in applying the more thorough treatments may be prohibitive, especially if the available woods have sufficient natural durability to insure a reasonably long life in service. In most cases, however, the treating charges constitute only a small to moderate percentage of the cost of the completed installation. Thus, one of the largest pole-using companies in New England estimates that the charges for creosoting southern pine poles are about 15 per cent of the total cost of the timbers in line. Available figures for crossties (Table XVI) indicate that the expense of treatment ranges from 22 to 36 per cent of the total cost of the ties in track.

Typical figures for wood used in coal and metal mines (Table XXI) show that the cost, in place, of treated timber is from 30 to 90 per cent greater than that of untreated material; but even the maximum additional expense is not considered excessive, in view of the increased service life to be expected from the treated wood. It was determined in one state (20) that, while the use of untreated-timber bridges might effect a saving of about 25 per cent in initial cost, such structures would probably have only about one-third the service life of similar bridges built of treated material.

The first cost, in place, of any construction item may vary extensively from time to time and in different localities, being influenced to a marked degree by variations in cost of materials and labor. In the case of a given treated-timber product, for example, the purchase price, alone, is dependent upon the species of wood, the specifications under which it is purchased, the method of treatment, and often, as a result of pronounced differences in transportation charges, upon the points of production and consumption. Furthermore, the price of a particular kind and size of pole, crosstie, or other item may fluctuate greatly within comparatively short periods of time, as the production and treating charges are altered by changes in costs of labor and preservatives. It is impossible, therefore, to derive any single set of cost figures that are applicable to a given region for any considerable period of time.

A few cost figures reported by railways for ties are given in Table XVI. Charges for interest, taxes, insurance, depreciation, freight over company lines, and inspection are usually omitted from such data, although they should properly be included in computing the cost of a tie in place. The expense of inserting ties in track is more variable than is indicated, being influenced, to a marked degree, by the character of the ballast, density of traffic, use of labor-saving machinery, wages paid, and efficiency of the crew making the installation. A charge of approximately 40 cts. per tie is assumed to be a reasonable average figure for installation.

SERVICEABLE LIFE

The length of time that a given structure or construction item remains in serviceable condition is of major importance in deter-

TABLE XVI.—TYPICAL COST FIGURES FOR RAILWAY TIES (1935)

Species of wood	Red oak	Douglas fir	Douglas fir	Red oak	Southern pine	Southern pine	Oak and gum	Ponderosa pine	Douglas fir
Size	6″ × 8″ × 8′	6″ × 8″ × 8′	7″ × 9″ × 8′	7″ × 9″ × 8′6″	7″ × 9″ × 8′6″	7″ × 8″ × 8′	7″ × 8″ × 8′	7″ × 8″ × 8′	7″ × 8″ × 8′
Treatment.									
Preservative and absorption	Creosote, 5.3 lb per cubic foot	Creosote-petroleum, 9 lb. per cubic foot	Creosote-petroleum, 9 lb per cubic foot	Creosote-coal-tar solution, 7.5 lb per cubic foot	Creosote-coal-tar solution, 7.5 lb. per cubic foot	Creosote-petroleum, 8.6 lb per cubic foot	Creosote-petroleum, 8 lb. per cubic foot	Creosote-petroleum, 8.3 lb. per cubic foot	Creosote-petroleum, 8.5 lb. per cubic foot
Cost of untreated tie at treating plant	$0.502	$0.40	$0.52	$0.765	$0.695	$0.554	$0.849	$0.844	$0.692
Cost of treatment	0.395	0.32	0.42	0.475	0.475	0.425	0.493	0.423	0.315
Miscellaneous costs*	.			0.172	0.172	0.046	0.061	0.057	0.042
Cost of installation	0.200	0.40	0.40	0.400	0.400	0.416	0.428	0.422	0.413
Total cost in the track	1.097	1.12	1.34	1.812	1.742	1.441	1.831	1.746	1.462

* Interest, taxes, insurance, depreciation, freight over company lines, etc. Although these items are a part of the actual costs, they are often not given, are included in the other figures, or are not known.

mining the ultimate economy of the material involved. Although chiefly dependent upon the inherent permanence of the material itself, the period of usefulness may also be greatly influenced by structural design, construction details, and maintenance. For example, the design and construction of the old-style covered wooden bridge made this type of structure very long-lived, even though it was built of untreated material. The significant factor was the housing over the bridge members, which kept much of the wood relatively dry and thus free from decay. The use of inadequate tie plates, or the complete omission of such protective devices in railway tracks, may lead to severe rail cutting of ties and thus materially shorten the useful life of treated timbers. The life of wooden ties may also be curtailed by improper tamping of ballast, failure to adze and bore timbers before treatment, inadequate absorption or penetration of preservatives, and other causes. The effect of adequate maintenance in prolonging the serviceable life of a wooden structure is evident, for it is apparent that neglect of decay or insect infestation may lead to accelerated deterioration in any type of timber construction.

Although it is not possible to predict, with any degree of accuracy, the actual period of service that may be obtained from a given installation of timber (or a completed timber structure), experience is gradually indicating the approximate average life that may reasonably be expected from certain species of wood, methods of protection, and conditions of use. Service records for treated and untreated ties, poles, and fence posts are accumulating in considerable volume, but similar data on other timber products are relatively few and very inadequate.*

While it is conceded that modern steel and concrete structures and construction products will afford greater permanence than treated timber in many types of installation, the justification, for example, of assuming a service life of 60 years for a concrete bridge or 50 years for a steel pole remains to be proved. Moreover, as will be pointed out in the subsequent discussion of obsolescence, the full life of the more permanent forms of construction may never be realized, because changing requirements of service may often necessitate their earlier abandonment.

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* For detailed information concerning the life of various treated and untreated wood products, the reader is referred to the reports of the several committees on service records of the American Wood-Preservers' Association, particularly those published in the more recent proceedings of the annual meetings of the association.

ANNUAL CHARGE

Cost per year of service, or annual charge, is the most important of the various factors that should be considered in selecting the kind of material to be used in building a given structure, when economy is not overshadowed by special considerations. Annual charge is defined (15) as "the cost per year or the annual payment required to extinguish an interest-bearing debt during a period of years corresponding to the life of the . . . material in service." If it is assumed that capital is borrowed at interest to pay for the material in place, the annual charge can be computed by means of the following amortization formula:

$$
\begin{aligned}
A &= P\left(\frac{r(1+r)^n}{(1+r)^n-1}\right),\\
&= P\left(r+\frac{r}{(1+r)^n-1}\right),
\end{aligned}
$$

in which A is the annual charge, or cost per year; P is the first cost of the material (in place); r is the rate of interest (expressed as a decimal); and n is the number of years of service expected from the given installation. Tedious calculations can be avoided by compiling a schedule that shows at a glance the annual charges on each dollar invested, for various rates of interest and periods of service. Such a schedule is given in Table XVII.

The application of Table XVII may be illustrated as follows: Assume that a bridge fabricated from untreated timbers costs $10,000 to construct and has an estimated service life of 8 years. The annual charge for this structure, at 4 per cent interest, would be 0.1485278 × $10,000, or $1,485.28. If treated timbers were used in the construction, the first cost might reach $14,000, but, with an expectant life of 30 years, the annual charge at 4 per cent would be but 0.0578301 × $14,000, or $809.62. On the other hand, if it were decided to erect a monumental concrete structure costing $30,000 and having an estimated service life of 60 years, the annual charge would be $1,326.05. Even though the concrete bridge might last 100 years, the annual charge would be

TABLE XVII.—ANNUAL CHARGE ON EACH UNIT EXPENDITURE FOR MATERIAL IN PLACE*

Life before replacement n, years	Interest rate		
	r = 3 per cent	r = 4 per cent	r = 5 per cent
1	1 0300000	1 0400000	1 0500000
2	0.5226108	0 5301961	0 5378049
3	0 3535304	0 3603485	0 3672086
4	0 2690270	0 2754900	0 2820118
5	0 2183546	0 2246271	0 2309748
6	0 1845975	0 1907619	0 1970175
7	0 1605064	0 1666096	0 1728198
8	0 1424564	0 1485278	0 1547218
9	0 1284339	0 1344930	0 1406901
10	0 1172305	0 1232909	0 1295046
11	0 1080774	0 1141490	0 1203889
12	0 1004621	0 1065522	0 1128254
13	0 0940295	0 1001437	0 1064558
14	0 0885263	0 0946690	0 1010240
15	0 0837666	0 0899411	0 0963423
16	0 0796108	0 0858200	0 0922699
17	0 0759525	0 0821985	0 0886991
18	0 0727087	0 0789933	0 0855462
19	0 0698139	0 0761386	0 0827450
20	0 0672157	0.0735817	0 0802426
21	0 0648718	0 0712801	0 0779961
22	0 0627474	0 0691988	0 0759705
23	0.0608139	0 0673091	0 0741368
24	0 0590474	0 0655868	0 0724709
25	0 0574279	0 0640120	0 0709525
26	0 0559383	0 0625674	0 0695643
27	0 0545642	0 0612385	0 0682919
28	0 0532932	0 0600130	0 0671225
29	0 0521147	0 0588799	0 0660455
30	0 0510193	0 0578301	0 0650514
35	0 0465393	0 0535773	0 0610717
40	0 0432624	0 0505235	0 0582782
45	0.0407852	0 0482625	0 0562617
50	0 0388655	0 0465502	0 0547767
60	0 0361330	0 0442018	0 0528282
70	0 0343366	0 0427451	0 0516992
80	0 0331117	0 0418141	0 0510296
90	0 0322556	0 0412078	0 0506271
100	0 0316467	0 0408080	0 0503831

* Based on formula $A = P\left(\frac{r(1 + r)^n}{(1 + r)^n - 1}\right)$.

$1,224.24, or 51 per cent more than that of the much shorter-lived treated-timber structure.

The values given in Table XVII can also be used to determine the minimum service life that treated wood must have in order that its cost of amortization shall not exceed that of the cheaper, untreated timber. For example, if the cost, in place, of an untreated mine tie is $0.98, and that of a treated tie is $1.23 (10), how long must the treated timber last in order that the annual charge shall be the same as that for the untreated one? Assuming that an untreated tie has a service life of 3 years, its annual charge at 4 per cent interest will be $0.98 × 0.3603485, or $0.353. Since the treated timber is to carry the same annual charge, we can set up the equation

$$\begin{aligned} 1.23 \times y &= 0.98 \times 0.3603485, \\ y &= 0.2871069, \end{aligned}$$

in which y is the annual charge per unit (dollar) expenditure for the treated tie. Referring to the 4 per cent interest column in Table XVII, we find that for an annual charge of 0.2871069 per dollar, a life of less than 4 years is required. A properly treated mine tie should last much longer than this and, consequently, should carry a much lower annual cost than the foregoing. Thus, a life of 15 years for a treated tie costing $1.23 would give an annual charge of about $0.111, or less than one-third that of a $0.98 untreated timber.

COST OF MAINTENANCE

In the foregoing discussion of annual charges, no consideration was given to maintenance costs. Although such expenses may not influence the ultimate cost of piles or other individual construction members, they are often significant when applied to bridges or other complete structures. An untreated timber structure usually requires frequent repairs if it is to be kept in usable condition, and, in some cases, the maintenance costs may be so high, after a few years of service, that it is more economical to rebuild the entire structure with more durable materials than to continue to renovate it. A specific example of excessive maintenance cost is reported (24) in the case of certain barges, in which untreated bulkhead timbers, originally costing $220, required replacement after 6 years of service. The expense of replacing these timbers, exclusive of the cost of the new material, was estimated at $2,100, including a charge of $600 for loss of service of the barge while undergoing repairs.

There is but scanty information pertaining to the relative cost of maintenance of treated and untreated wood structures. The bridge engineer of a large western railway system, in referring to the situation with regard to timber bridges, stated in 1922 (19): "Even when we had good white oak for piles we seldom got more than from eight to twelve years of safe life. We had to spend from 5 to 50 cents a foot per month to maintain the bridges after a few years went by. Compare that now with our creosoted ballast deck bridges that have stood for years and years and then have not cost ten dollars on one hundred feet per year."

In a more recent report (21), it was stated that, during a period of 24 years, the annual average maintenance cost on a group of 129 ballasted-deck creosoted railway bridges in Louisiana varied from less than 1 ct. per linear foot during the first year to a maximum of 43 cts. per foot during the sixteenth year of service. The arithmetical mean was approximately 20 cts. per foot per year. The average initial cost of bridges of this type was about $45 per linear foot.

Numerous other examples of low maintenance costs of creosoted timber structures have been recorded, but there is a dearth of data on comparable structures built of materials other than wood.

OBSOLESCENCE

In the face of present-day economic and social developments, structures that are models of design and equipment when first built often become obsolete after a few years of service. This factor of early obsolescence may be an important consideration in the selection of construction materials, since it is obviously unprofitable to build an expensive structure and abandon it within from 10 to 20 years because it has become antiquated in design or is inadequate in size or inexpediently located. Likewise, it is often uneconomical to continue to use a structure after it has become unsuited for the required purpose.

Changes in highway location, to avoid railway crossings, shorten distances, reduce grades, or eliminate curves, have frequently necessitated the abandonment of existing bridges and culverts. When such structures are made of creosoted wood, the timbers can be recovered and often used again; but when built of steel or concrete, the material has little or no salvage value, and the bridges and culverts either must be left as monuments to obsolescence (Fig. 68), or must be destroyed at considerable cost. Pole lines, guard-rail installations, and property-fence lines are also included among the structures that are subject to removal or abandonment, when highway routes are altered or other progressive changes are made. The widespread substitution of motor-bus for street-railway service in certain sections of the country has often necessitated the wholesale abandonment of trolley poles, which are frequently made of iron and have low salvage value. The communication field is one in which potential obsolescence is often recognized, with reference to pole use. Experience indicates that changing civic or traffic requirements, or other developments, may often cause the eventual replacement of overhead construction with underground conduit, the relocation of lines, or the use of larger poles capable of supporting greatly increased loads. Consequently, there is every reason to question the wisdom of spending extra money on a pole line, in order to obtain an expected life of 100, or even 50 years. In fact, it is recognized that lines of the present timber construction may become obsolete before the treated poles attain their full average life.

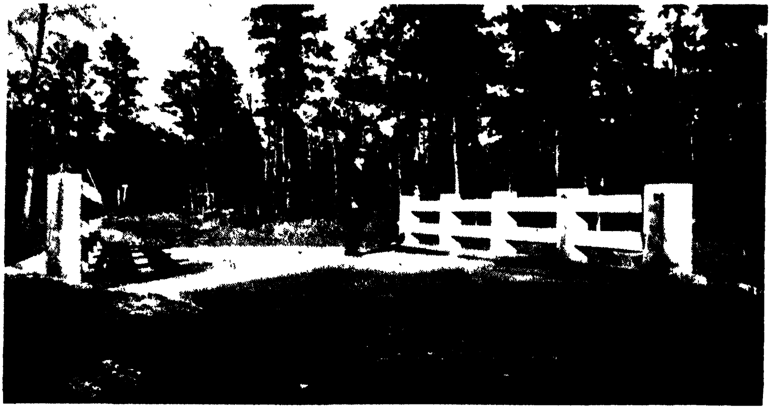

FIG. 68.—Concrete bridge abandoned when highway was rerouted.

There has been a great increase in the frequency and speed of vehicular travel over the highways of the country in recent years, and a widespread use of heavily loaded buses, trucks, and trailers. These unprecedented traffic conditions have necessitated a rather general widening of highways and strengthening of bridges, many of which, when first constructed, were considered adequate for future needs. Bridges and culverts of treated wood have a definite advantage in such a modernization program, since they can be widened, strengthened, or replaced at moderate cost and with little interruption of traffic, as compared with similar steel and concrete constructions. Treated wood is an especially desirable material to use in building such highway structures when there is a possibility that changes will be required within 20 to 30 years.

The rapid increase in the size of the ships built during the last few decades has necessitated frequent enlargements in harbor structures, in order to provide proper docking facilities. The situation in the marine field is well illustrated by the following extract from a report made in 1919 by the chief engineer of the Board of State Harbor Commissioners of California (11):

> As evidence of the rapidity of the changes that have taken place in ocean transportation in the last few years and the constant need for new types and larger dimensions for piers, the experience of San Francisco may be adduced. Prior to 1909, the standard pier was 80 feet wide and 600 feet long; it became necessary, on account of deterioration, to replace some of the older structures and it was decided to build for future increase of traffic and to erect permanent piers of sufficient size to handle it. The new piers were 130 feet to 140 feet wide and 650 feet to 700 feet long with 200-foot to 220-foot slip spaces as against 150-foot to 200-foot slip spaces previously deemed ample. In 1912, before commencing the construction of four new concrete piers, a large number of shipping men were consulted and in accordance with their views the piers were made 200 feet wide and 800 feet long with 250-foot slips. Two or three months ago plans were prepared for a new improvement at the southerly end of the waterfront involving several piers 235 feet in width by 1000 feet in length with 300-foot slips. In other words, in ten years the demands of commerce have increased pier width by about 80 per cent, pier length by 50 per cent, and slip width by 50 per cent; the structures thought ample at the beginning of the ten-year period have become inadequate but must remain in service because they are too expensive to be torn down and the new idea of size required cannot be adjusted to existing piers.

A recent statement by the chief engineer of the Department of Docks of the City of New York (18) further emphasizes the repeated outgrowth of docking facilities by the continually expanding marine traffic. This report traces the steady increase in pier sizes from 1872, when a dock 450 ft. in length was provided for the *Oceanic*, to 1935, when a dock 1100 ft. long and 400 ft. wide was required to accommodate the *Normandie*. It is interesting to note that past experience in steamship-pier construction in New York Harbor has led to the extensive use of creosoted timber in present-day structures.

SALVAGE VALUE

When the salvage value of the more permanent construction materials is considered, treated wood is generally conceded to have a definite economic advantage over steel and concrete. When it is necessary to dismantle or remodel a timber structure that has become obsolete before attaining its maximum service life, much of the treated wood can usually be reclaimed at little cost and reused, either in a new location or on the remodeling job (Fig. 69). Steel, also, may sometimes be recovered from obsolete structures but seldom to so great an advantage or at so

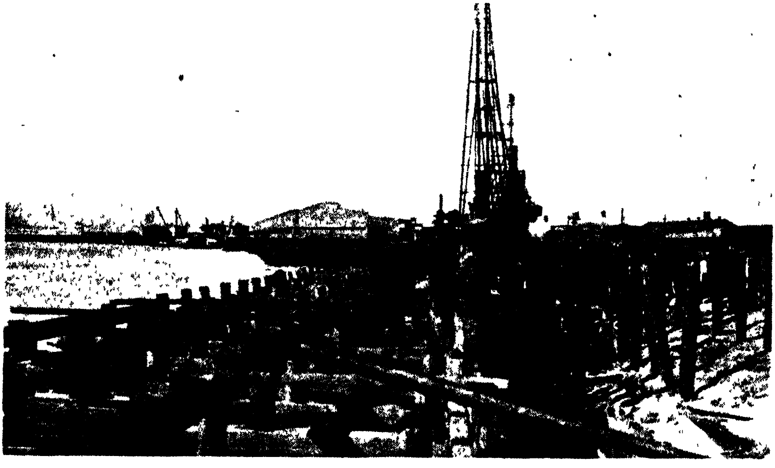

FIG. 69.—Redriving salvaged creosoted piles in a new wharf after 20 years' service in a previous structure.

little expense as timber. Concrete, on the other hand, has no salvage value and is also very expensive to remove when a structure must be demolished.

A good example of the salvage value of treated timber is provided by the Oakland (Calif.) Long Wharf, construction of which was started in 1889 and completed in 1900. When the wharf was dismantled in 1918, in order to permit changes in the harbor facilities, all of the 15,000 creosoted piles originally driven to support the structure were intact. Despite their continuous service over periods of 18 to 29 years, a large proportion of the piles were in such good condition that they were reused in building new docks and wharves in the vicinity (17). Some of these piles were driven where they could be kept under observation, and, at last report, most of them were still serviceable, after 34 to 45 years of exposure in waters infested with marine borers.

When the Santa Monica (Calif.) Long Wharf was built in 1891 and 1892, a total of 132,000 lin. ft. of creosoted Douglas fir piling was used in its construction. This wharf was dismantled between 1916 and 1921, because of the development of the Port of Los Angeles, and many of the piles were salvaged and reused in building various marine structures in the vicinity. Some of them were placed in the foundations of one wing of the Sunset Pier at Venice, Calif., and, when one section of the latter structure was remodeled in 1929, approximately 60 of the old salvaged piles were removed. All but one of these timbers were found to be so sound, after 38 years of service, that plans were made to sell them for use a third time (5).

When changes in levee grade made it necessary to reconstruct the 19-year-old Celeste Street Wharf in New Orleans in 1923, about 70 per cent of the creosoted piles that had supported the 1200-foot structure were in such good condition as to warrant their reuse. Part of the reclaimed timbers were redriven in the new wharf, and the remainder were utilized in other locations (27). The other 30 per cent of the timbers were rejected because decay had developed in the tops, due to improper protection of the pile heads when they were cut off to grade at the time of the original construction. In 1928, levee grade changes also necessitated the remodeling of another New Orleans marine structure, the St. Andrews Street Wharf, which had been built of creosoted material in 1907. In this case, a very large proportion of the original timbers (piles, laminated timber caps, and stringers) were employed in the reconstruction work (13).

Although wharves have provided most of the recorded examples of the salvage value and reuse of treated wood, they are by no means the only structures to demonstrate the suitability of such material for reuse. Bridges, trestles, pole lines, railway track (Fig. 70), and various other forms of timber construction also afford striking illustrations. An interesting instance was reported (3) in the case of a section of street-railway track, originally laid in Main Street, Memphis, in 1905 and 1906. Inspection of the track in 1929, in connection with a program of street improvement, disclosed the fact that, although the steel rails required replacement, the creosoted crossties were practically all in excellent condition and suitable for reuse, after 24 years of continuous service. These ties were salvaged and relaid in a modern paved track, after the spike holes had been filled with plugs made from old creosoted wood paving blocks; they were

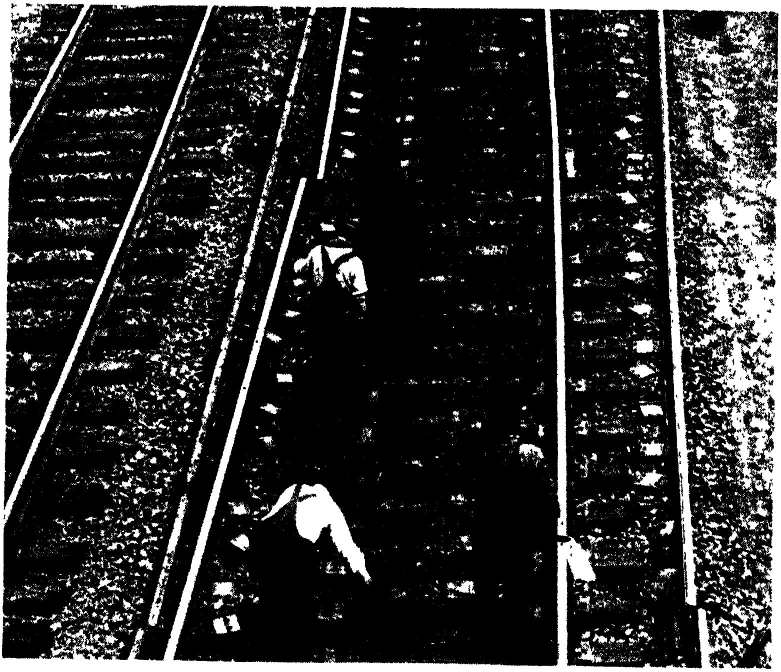

FIG. 70.—Installing new rail and tie plates on old creosoted ties.

laid with the plugged faces down, the new rail being spiked to the original bottom surfaces of the ties. It was anticipated that these 24-year-old crossties would have a further service life equal to that of the new rail—"probably 20 years." A final conspicuous example of the adaptability of treated timber to reconstruction work may be cited in the case of the 8000-ft. viaduct, between Kansas City, Mo., and Kansas City, Kans. (4). This structure, built in 1905–1907, was modernized in 1936 to meet the needs of increased traffic between the two cities. The 31-year-old wooden foundation piles under the original piers of the viaduct were in such good condition that they were used to support the remodeled structure. Of the 3,371 piles originally driven, 2573 had been treated with 12 lb. of creosote per cubic foot of wood; the remainder, used under conditions that insured their being permanently saturated with water and hence not subject to decay, had not been treated.

The examples cited serve to emphasize not only the possible reuse of adequately treated wood but also the ready adjustment of timber construction to changing service requirements and the relative ease with which alterations can be made. The salvage value of a dismantled structure may be credited against its total cost over the period of years during which it was in service, thus tending to reduce the actual annual charge.

IMPORTANCE OF TREATED WOOD TO RAILWAYS

In the early days of railway development in the United States, when mileage was small and labor and materials relatively cheap, there was little concern about extending the life of the necessary structures beyond that provided by timbers which were durable by nature and usually available in abundance near the construction sites. The situation became definitely altered, however, as the transportation systems expanded. The steady growth in railway mileage added materially to the number of structures that had to be built and maintained, and the annual consumption of timber became so great that the readily accessible supplies of acceptable woods were seriously depleted. It often became necessary to transport materials for considerable distances and in some cases to import them from other regions. The resultant increases in timber prices were also accompanied by continually mounting costs of other necessary materials and of labor. Increased traffic also imposed more exacting requirements as to size, strength, and quality of the acceptable wood products, and this, in turn, added to the initial costs of the various items. Competition with other forms of transportation finally reached a point where it became more and more urgent to secure maximum economy in operating costs.

The inevitable result of the demand for greater economy was to direct attention to the development of more permanent forms of construction, and the railways were forced either to find satisfactory methods of increasing the life of structural timber or to abandon its use in favor of steel or concrete. Although the latter procedure has been adopted in some cases, notably for large bridges, platforms, and buildings, the application of preservative treatment has so reduced the ultimate cost of wood that it is still the approved material for most railway structures. Today, treated timber is extensively used not only for crossties, which for years have constituted the bulk of the wood treated annually in the United States, but also for switch ties, piles, poles, and various wooden members used in the construction of bridges, trestles, docks, and wharves. The railways also are using considerable quantities of a miscellaneous assortment of treated wood for such purposes as crossing planks, water tanks, car material, loading platforms, scale houses, sign boards, fence posts, signal-box material, general building lumber, and wood-block floors.

The crosstie affords an excellent example of the economic benefits of preservative treatment. White oak heartwood was the preferred material throughout the East for many years. This wood has excellent mechanical properties and moderate durability, giving an average life of from 8 to 12 years in its natural condition. Douglas fir was the principal tie wood in the Pacific Coast and Rocky Mountain states, and heart longleaf pine was extensively used in the South. Both of these species were available in large quantities and relatively inexpensive; when used under favorable conditions, they had an untreated service life of as much as 8 years. The more durable woods, including the cedars, cypress, chestnut, and redwood, were also used extensively and gave an average life of 12 to 15 years when not subjected to severe mechanical wear. In contrast to these timbers, crossties made from most of the other available species had a life of only 2 to 5 years in track and, consequently, were not economical to use, even when relatively low in first cost. The early experimenters soon discovered, however, that the cheap, nondurable woods could be impregnated with preservatives and made to last as long as the naturally durable, untreated timbers. Subsequently, as preservatives and treating methods were improved and service records were accumulated, it was found that these treated ties were remaining in track, on the average, from two to four times longer than the untreated white oak, Douglas fir, and longleaf pine timbers. Furthermore, it soon became evident that the life of the moderately durable ties could also be increased two- to three-fold by preservative treatment.

The marked effect of preservative treatment in increasing the service life of crossties has resulted in a definite decrease in the cost per year of service (annual charge) of these timbers. The following general examples will serve to illustrate this point. If we assume that the various kinds of crossties that are now generally used in an untreated condition have an average first cost in track of $1.40 and an expectant average life of 7 years, the annual charge, at 5 per cent interest, would be $0.242 per tie. On the other hand, the charge for the average treated tie, having an assumed cost in track of $1.80 and an expectant life of 20 years, would be $0.144. The indicated annual saving, effected by the complete use of treated crossties, would thus be about $294 per mile (3000 ties) of single railway track. Even assuming that the railways were able to secure enough high-grade white oak ties to supply their needs and that such ties could be placed in track, untreated, for $1.50 each and would have an average expectant life of 10 years, the annual charge at 5 per cent interest would be $0.194 per tie. Compared to this, the most expensive tie listed in Table XVI (cost in track, $1.831) would have an annual charge of but $0.147, for an expectant life of 20 years. Recognized service records and modern conditions of use indicate that the above-estimated average life of the treated ties is definitely more conservative than that of the untreated timbers.

REDUCTION IN ANNUAL TIE REPLACEMENTS

Prolongation of the average life of crossties by preservative treatment has naturally resulted in the use of fewer ties per year per mile of track (2, 14). Table XVIII shows the remarkable progress made in reducing annual tie replacements by the principal railways in the United States, which control almost half the total track mileage in this country. The 5-year averages shown in the last column of this table were obtained by averaging the annual renewals for the year indicated with those of the 4 previous years. The replacement figures thus obtained show much less fluctuation than the current annual renewals, and give

TABLE XVIII.—CROSSTIE RENEWALS PER MILE OF TRACK* (2, 14)

Year	Number of railroads reporting	Total miles of track reported	Average number of ties replaced per mile	
			Current year	Last 5 years
1911	22	136,129	262	249
1912	24	155,680	241	248
1913	25	163,427	259	251
1914	26	178,852	255	251
1915	26	181,274	265	256
1916	26	182,963	249	254
1917	27	190,486	206	247
1918	27	192,773	193	234
1919	27	193,807	203	223
1920	27	196,045	210	212
1921	27	196,720	211	205
1922	27	197,297	202	204
1923	27	198,882	198	205
1924	27	201,696	182	201
1925	27	203,330	188	196
1926	27	204,654	183	191
1927	27	198,692	185	187
1928	27	199,452	184	184
1929	27	200,715	176	183
1930	27	201,481	152	176
1931	27	200,492	117	163
1932	27	201,782	83	142
1933	27	201,454	73	120
1934	27	200,483	95	104
1935	27	199,231	95	93

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* Based on installations made in all track maintained by the principal railroads in the United States.

a more uniform indication of the general trend. An average of 256 ties was required annually to maintain each mile of track belonging to the railways under consideration during the 5-year period ending in 1915 and prior to the major expansion in the use of treated timber. The average yearly renewals per mile, for a like period ending in 1929, were 183 ties, there being a general steady decline of approximately 30 per cent below the 1911–1915 requirements. The 5-year averages have fallen off rapidly since 1929, because of the great reduction in railway income during the depression and the consequent lack of funds with which to purchase ties. The high percentage of treated ties in the tracks of many of the roads was of great economic advantage during this period, because it permitted such companies to reduce track-maintenance expenses much more than would otherwise have been possible. During these years of financial stress, some of the railways, which had previously made extensive use of treated material, adopted a policy of making practically all replacements with untreated ties, in order to reduce maintenance costs further. This practice will prove to be false economy in the long run, for the relatively short service life of the untreated ties will make their cost per year considerably higher than that of well treated material.

The averages shown in Table XVIII are based, in part, on the renewal data of a number of railroads that have used treated ties longer than others and have a higher percentage of such timbers in track. Furthermore, some of these roads have also used better preservatives and more thorough treatments than others and have paid greater attention to providing adequate mechanical protection to the ties. As a result, the annual renewals for those companies which have been most progressive in the use of treated material are much lower than the general averages. There is every reason to believe that an average service life of 25 years and more can be attained by ties that are adequately impregnated with superior preservatives and given suitable mechanical protection. Hence, it is evident that, when all the ties in the track of any railway are so treated, the annual renewals should eventually be reduced to 120 or less per mile (3000 ties). The requirements of a number of companies are already appreciably below this figure. For example, the annual crosstie replacements of the Delaware, Lackawanna, and Western Railroad have been less than 100 per mile since 1923, and in 1935 the 5-year average of the road was only 70 ties. The Lehigh Valley Railroad has kept its average annual replacement below 100 ties since 1924 and had a 5-year average of 59 in 1935. The New York Central Lines West and the Central Railroad of New Jersey have similar records. In direct contrast to these roads, other companies have had difficulty in getting their renewals as low as 150 per mile, even during the worst depression years, and their lowest 5-year averages have not been much below 200 ties. This situation placed the latter railroads at a distinct financial disadvantage during the years of low revenue.

When the reductions in average annual renewals per mile of track are considered from the point of view of the entire mileage of a large railroad, or a group of railroads, the derived financial benefits are striking. Thus, in the case of the Baltimore and Ohio Railroad, the decrease from the 275 ties required during the 5-year period 1912–1916 to the 152 ties used in 1929 is estimated to represent a saving of $2,362,000 in the last-named year alone. During 1927, the actual replacement requirements for the Class I railroads in the United States totaled about 78⅓ million ties, representing the equivalent of an average service life of 13½ years for the 1,047 million crossties in the tracks of these roads, less than 70 per cent of which were treated. Based on an average life of 10 years for untreated ties, and 1929 materials and labor costs, the saving to these railroads has been appraised at $145,000 per day. If, however, all of the ties in track had been so treated as to have an average life of only 20 years and had been in service long enough for renewal requirements to have become stabilized, only about 52⅓ million crossties would have been required for replacement purposes. On this basis, the daily saving would have been approximately $287,000. (8.)

AVERAGE LIFE OF TIES AND PERCENTAGE RENEWALS

Thorne (25) and McLean (16) have shown that the percentage of ties replaced in any group up to a given time and the number of years the group has been in service at that time bear a close relationship to the average life of the ties. From such data as these it is possible to calculate not only the probable average life that will be attained by the entire group but also the approximate number of ties that will require replacement during each

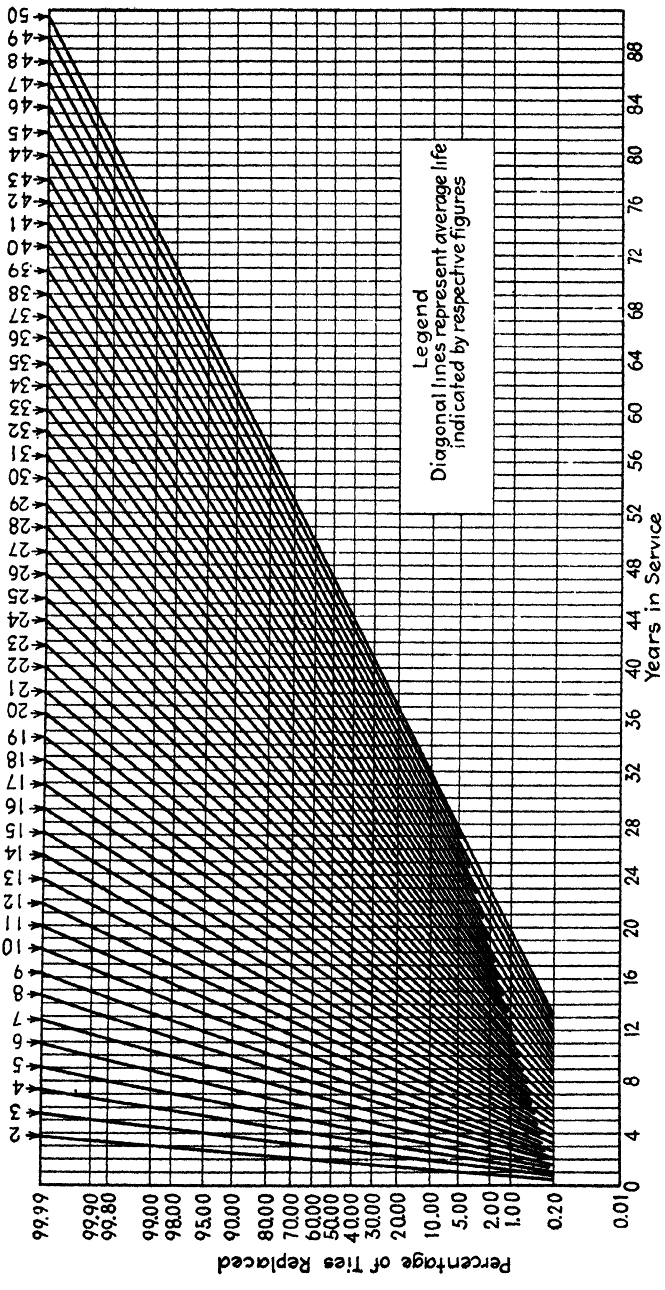

FIG. 71.—Chart for determining probable average life of ties from percentage removed and years' service to date. (*U.S. Forest Products Laboratory.*)

subsequent year, so long as any members of the group remain in service. The correlations hold for both treated and untreated ties. Figure 71 is a simplified chart, prepared by MacLean, which shows these relationships for average life periods of up to 50 years. The use of the chart is illustrated by the following example:

Assuming that, for a given lot of ties, 20 per cent have been removed at the end of 17 years of service, what will be the average life of the entire group? Referring to the chart, it will be seen that the vertical line for 17 years' service intersects the horizontal line for 20 per cent renewals on the diagonal representing 23 years' average life. Thus, the ties in the group under consideration may be expected to have an average life of 23 years. It will be noted on the chart that the approximate average life of any group is reached at the time when about 60 per cent of the ties have been removed.

Furthermore, by noting the points at which a given average-life line is intersected by the vertical lines, representing successive years of service, it is possible to obtain an indication of the number of ties that will need to be removed each year. For example, it will be observed that the 23-year average-life line intersects the successive vertical lines for 18 to 26 years of service at points indicating the following approximate total replacements, respectively:

Length of Service Period, Years	Total Replacements for Average Life of 23 Years, Per Cent
18	26
19	32
20	38
21	46
22	53
23	61
24	67
25	74
26	80

The number of ties to be renewed in any one of the selected years can then be calculated by multiplying the total number of ties originally placed in track by the indicated increase in percentage of total replacements for that particular year. Thus, for the 23-year average life under consideration, if there had been 10,000 ties in the original group, 6 per cent, or 600 ties, would need to be replaced during the twentieth year of service; and 8 per cent, or 800 ties, the following year.

It must be recognized that the average-life figures and the forecasts of renewals obtained in this way are only approximations. Individual groups of ties may give actual service results that vary to some extent from those indicated by the chart, especially if the groups are small or the percentage renewals are low (below 10 or 15 per cent). However, the general experience of railways making large installations of ties has been that such forecasts are very reliable approximations after 10 per cent or more of the original ties have been removed.

Substitute Ties

The superiority of wood over other structural materials is probably nowhere shown to greater advantage than in the cross-tie field. Innumerable attempts have been made in the United States to invent a satisfactory substitute for the wood tie, and the American Railway Engineering Association has investigated all that showed any promise of being satisfactory. No material or design has yet been developed, however, that gives such good service and is so economical as treated timber. A great deal of work has been done with reinforced concrete, presumably because of its appropriateness for so many other types of construction, but ties made of such material have often been found to have a relatively short mechanical life and proved to be otherwise generally unsatisfactory. Somewhat better service results have been obtained with steel ties, but these, too, have a number of distinct disadvantages, aside from their high initial cost. Among the outstanding objections to the steel ties are such factors as lack of resistance to corrosion, difficulty of maintaining adequate rail fastenings, difficulty of properly insulating track circuits, and lack of resilience and resultant inability to withstand loads imposed by modern high-speed traffic.

Steel ties are used to a considerable extent in some European countries, notably Germany and Switzerland, although apparently not entirely because of their technical merits. They have also found wide use in India, a condition that may be attributed, at least in part, to the fact that the wood-preserving industry in that country has not yet been developed to the point where it can produce adequate quantities of satisfactorily treated wood ties.

The development of the industry, in turn, has been greatly hampered by the fact that coal-tar creosote is not manufactured in India but must be imported at considerable expense.

In the United States, the peak of production and use of ties other than wood was reached during the years 1921–1923, when an average of about 500,000 substitute ties were laid in track each year. These were undoubtedly almost all of steel, for concrete ties have never been used in quantity in this country. Large as this number appears to be, it represents less than 1 per cent of the total of all ties laid during the 3 years referred to. Since 1923, the installation of ties other than wood has been insignificant. The records of the Interstate Commerce Commission show an average annual consumption of 12,300 such ties for the years 1924–1934, inclusive, with the greatest number, 21,724, being used in 1928.

ECONOMIC IMPORTANCE OF PRESERVATIVE TREATMENT FOR PRODUCTS OTHER THAN TIES

Data similar to those in Table XVIII are not available for posts, poles, piles, bridge timbers, and other structural forms of wood, but it is known that treatment of these products is resulting in the same trends toward fewer replacements and lower annual charges. The economic advantage derived by these wood products from preservative treatment is perhaps most strongly attested by their continued extensive use, despite the many improvements made in competing materials.

Posts

Treated wood posts have proved to be so well suited for railway and highway property-line fencing that they are extensively used for such purposes, despite the keen competition offered by steel products. Wood posts are stronger than steel members of the sizes commonly used and offer greater resistance to overturning. On the other hand, steel posts can generally be set more easily than wooden ones and, consequently, usually cost less to put in place. Concrete posts are so much heavier, larger, and more expensive than wood or steel that they do not afford much competition in this field.

The relative cost in place of wood, steel, and concrete fence posts varies so much in the several sections of the country and under different circumstances of use, that accurate comparisons are not available. The following estimates, made in 1924 by the Committee on Signs, Fences, and Crossings of the American Railway Engineering Association (1) were compiled from data obtained in a survey by questionnaires:

TABLE XIX.—AVERAGE LIFE AND COST ESTIMATES FOR POSTS OF DIFFERENT MATERIALS

Kind of post	Estimated average life, years	Cost installed	Annual cost (interest at 6 per cent)
Concrete	50	$0.70	$0.044
Steel	22.5	0.58	0.047
Wood:			
Average	23.7	0.52	0.041
Cedar	23.9	0.50	0.040
Shortest life	12.0	0.41	0.048
Longest life	30.3	0.38	0.027

The preceding estimates for wood posts were based very largely upon experience with untreated timbers, and the average-life figures reported seem rather high for this class of material, although the 30-year average is probably not far from correct for full-length pressure-creosoted posts. The indicated life of 50 years for concrete was based on the assumption that such posts would be made according to improved design and manufacturing methods; a great many concrete posts used prior to the time the data were collected had given very inadequate service.

Wood is better adapted than either steel or concrete for highway guard-rail posts. The greater bulk of wood posts makes them more readily visible than steel members, while their ability to yield under impact and their lower cost make them preferable to concrete posts. Although accurate service data are lacking, the average life of treated-wood highway posts should be at least as long as that of poles of equal size and similar treatment, and probably considerably longer, if failures resulting from breakage by road machinery and automobiles are disregarded. Since there is even less authentic information for steel and concrete, it is not possible to make comparative annual cost estimates for the three highway-post materials.

The economy of treated posts for farm use is not always apparent. When abundant quantities of posts of naturally durable wood are available at low cost, which is still the case in many parts of the country, and treated timber is expensive or difficult to obtain, there is little incentive to buy treated posts or to build a creosoting plant for the home treatment of such products. In sections where there is a definite shortage of durable timber, on the other hand, the economy of using treated posts can be readily demonstrated, when all of the involved costs are considered. However, there is one aspect of the farm timber-use problem that makes it difficult to gauge properly the relative cost of treated and untreated material. Farmers who do their own work frequently consider direct cash outlays only and omit the cost of their own labor. When posts can be obtained for the cutting, hauled to the fence line, and set in place without an actual expenditure of money, it is difficult to show that treated posts, which require a definite initial cash outlay, are actually cheaper in the long run.

The expense of treating fence posts on the farm varies so widely that representative cost figures cannot be given. The chief factors are the price paid for the preservative, the amount used per post, the method of treatment employed, the cost of the treating plant, the number of posts treated, the wage costs, and the efficiency of the labor employed. When the treating is done in an inexpensive homemade plant, such as may be constructed out of secondhand materials, and the labor charges are not considered, the cost of the preservative becomes the principal item of expense. The cost of coal-tar creosote is subject to wide variation and may be as high as 50 to 75 cts. per gallon in small lots, delivered at the plant. This is roughly from three to five times the price paid in 1935 for distillate coal-tar creosote by large consumers buying in carload lots. When it is considered that a post should absorb from ½ to ¾ gal. of preservative oil for best results, it is easy to understand why so little farm creosoting is done. The cost of the preservative may be reduced by adding waste crankcase oil, fuel oil, gas oil, water-gas tar, or other cheap diluents to the creosote. However, some discretion must be used in making such mixtures, if the efficiency of the preservative is to be maintained.

POLES

The available information concerning costs and average-life estimates of steel, concrete, and wood poles is so inadequate that it is impossible to do more than generalize on the relative economy of these materials. The principal advantages claimed for steel and concrete poles are their good appearance, strength, and long life. Two of the recognized disadvantages are their great weight and high cost in place, in comparison with wood poles of equal strength. It is this initial cost, said to be from two to three times that of treated wood, that has undoubtedly prevented the extensive use of steel and concrete poles in the past.

Let it be assumed that a treated wood pole costs \$25, including the cost of setting in line, and that it has a service life of 25 years, while an equivalent steel or concrete pole costs \$50 in place and lasts 50 years. If the annual charges are calculated at 4 per cent. using the factors in Table XVII, the estimated cost per year will be \$1.60 for the wood pole and \$2.33 for the steel or concrete member. In order to have the same annual charge as the treated timber, the steel or concrete pole would have to be placed in line at a cost of only \$34.38:

$$\begin{aligned} \$25.00 \times 0.0640120 &= y \times 0.0465502, \\ 1.6003 &= 0.0465502y, \\ y &= \$34.38. \end{aligned}$$

Even if the steel or concrete pole had an anticipated service life of 100 years, the cost in place would have to be held to \$39.21 to give the same annual charge as the \$25 wooden pole.

The cedar poles used in building a 200-mile line in California in 1920 are reported to have cost \$69.50 each in place and were expected to have an average life of 20 years. Had steel poles been used on this job, they would have cost \$148.60 apiece when set in line. Under such circumstances, the annual charge for the steel structure would have been considerably higher than that for the wood, even if the steel poles were to last 100 years.

Various attempts have been made to prepare curves, similar to those for railway ties, by which the average life of a group of wood poles may be predicted from the percentage of the poles that have been replaced at any given time. While some progress has been made in this direction (9, 23), no generally acceptable curve or formula has yet been developed.

PILES

Steel, cast-iron, and wrought-iron piles have been employed to some extent in marine construction, but the usefulness of such products is definitely limited by their high initial cost, the care with which they must be driven to insure proper alignment of fittings and bolt holes for bracing, their susceptibility to breakage at the bracing points, and the relatively short lengths in which they can be used. Of the three materials, cast iron is considered to possess the greatest permanence, and has given excellent service in certain installations in San Francisco Bay. One lot of 145 such piles, made of 1-in. metal, measuring 12 in. in outside diameter and from 10 to 30 ft. in length and filled with concrete after driving, was placed in a pier at Alcatraz Island in 1870. Fifty-three years later, it was reported that more than half of the piles were still in service (11).

Concrete piles have been used much more extensively than metal ones, being available in larger sizes and much more adaptable to various forms of construction. The early types frequently gave poor service, especially in salt water, but subsequent improvements in materials, workmanship, and design have led to the development of much more satisfactory structural forms. Cast-in-place concrete pile jackets are considered less permanent than precast reinforced concrete piles and pile casings, while reinforced concrete cylinders of modern design and construction are exceeded in longevity only by solid fill or mass concrete (11). However, service records of these various forms of piling are still too inadequate to permit accurate determinations of their useful life.

Although both iron and concrete piles have given excellent service in certain installations, their first cost in place is usually so much higher than that of wood piles that timber construction is definitely more economical. The estimates given in Table XX on the relative economy of piles made of creosoted wood, reinforced concrete, and combined untreated wood and concrete were made by the San Francisco Bay Marine Piling Committee in 1927 and apply to salt-water use (11). The first costs will naturally vary with current prices and local conditions, and the figures in the table, which were based on pre-war contract prices, must be considered as illustrative only. The values in the third column, showing the annual cost of the several types of piling, were all computed for a service life of 25 years, which was considered to be a reasonable figure for creosoted Douglas fir. The figures in the fourth column, which afford a more significant comparison between the various materials, were all calculated from an annual cost corresponding to that of the creosoted wood piles.

TABLE XX.—COMPARATIVE COST ESTIMATES ON WOOD AND CONCRETE PILES FOR USE IN SAN FRANCISCO BAY (11)

Type of pile	First cost, per square foot of pier, installed	Total annual cost per square foot of pier, 25-year life*	Average life required to keep annual cost as low as that of creosoted wood, years
Pressure-creosoted wood piles.	$1 00	$0.1568	25
Reinforced concrete piles .	2.00	0 2185	41
Reinforced concrete cylinders	3.00	0.3248	Annual cost always higher than wood, even with infinite life
Untreated wood piles encased in reinforced concrete	1.85	0.2005	35.6
Untreated wood piles surrounded by precast reinforced concrete shells...	2.25	0.2426	50.4
Untreated wood piles encased in plain concrete...	1.40	0.1813	31.5

* Includes maintenance, insurance, interest at 5 per cent, sinking fund payment, depreciation reserve, and loss of revenue during reconstruction. No allowance is made for the salvage value of creosoted wood.

MINE TIMBERS

Although the adaptability and economy of treated wood for mine ties and various forms of underground timber have been repeatedly demonstrated in the past, comparatively little use is made of preserved wood in mines. Much of the apparent indifference of many mine operators to the recognized advantages of preservative treatment is doubtless due to the fact that a very large proportion of mine timber is used in temporary workings, such as rooms in coal mines and stopes in metal mines, which are kept open only a few months. Under such circumstances, the life of untreated wood is sufficient to meet the requirements of service, and, until satisfactory salvage methods are devised for items other than ties, the added expense of treatment will continue to be unwarranted. On the other hand, the general failure of operators to avail themselves of the opportunity to reduce timbering costs by utilizing treated wood in shafts, haulageways, and other permanent and semipermanent underground openings is difficult to understand.

A recent report (26) on 1926–1929 timbering costs in a number of large metal and anthracite and bituminous coal mines has provided some comparative figures for treated and untreated wood. The average cost of untreated timber, in the species, sizes, and quantities used in these mines, ranged from 20 to 40 cts per cubic foot, while the added cost of treatment and preservatives varied from 13 to 25 cts. per cubic foot, with a probable average of 17 cts. The installation charges were seldom less than 10 cts. per cubic foot and often considerably in excess of this figure, while the cost of replacement was usually two or more times that for the original installation. The service life of the untreated mine timber was found to vary from less than 2 to more than 10 years but usually did not exceed 2 to 4 years, while that of adequately treated wood was conservatively estimated as 12 to 15 years.

Some of the specific costs from which the preceding average figures were drawn are given in Table XXI. These data have been extended to include the relative annual charges for the two classes of material, based on a 4 per cent interest rate and an average service life of 3 years for untreated and 12 years for treated timber. The experience of the mines from which the tabulated cost data were obtained clearly indicates the savings that can be effected through the use of treated timber in underground locations in which the period of operation definitely exceeds the average life of untreated wood.

Additional economies in timber costs at mines can be effected by the use of treated wood above ground for track ties, trestles, flumes, breakers, tipples, ore bins, coal bunkers, and various

TABLE XXI.—EXAMPLE OF COSTS OF TREATED AND UNTREATED MINE TIMBER (26)

(For the years 1926–1929)

Type and location of mine and character of timber	Cost of timber delivered at mine		Labor cost of installation in new working	Labor cost of replacement in old working	Average cost in place*		Annual charge†	
	Untreated	Treated			Un-treated	Treated	Un-treated	Treated
Iron and copper mines (Mich.):								
Round tamarack, fir, 14 in. diam.:								
Three-piece set	$7 50 to 10 50	$11 25 to 13 75	$2 20 to 4 50	$7.00 to 9 00	$12 35	$15 85	$4 450	$1.689
Per cubic foot	0.30 to 0 42	0 45 to 0 60	0 09 to 0 18	0 28 to 0 38	0.495	0 66	0.178	0 070
Copper mines (Ariz.):								
Texas pine, 8 to 10 in. diam.:								
Three-piece set	3 75 to 4 25	5 50 to 6 50	1 75 to 2 50	4 50 to 6 00	6 125	8 125	2 207	0 866
Per cubic foot	0 30 to 0 36	0.45 to 0.50	0.12 to 0 20	0.35 to 0.50	0.49	0 635	0 177	0 068
Fir, 8 to 12 in. squared timber:								
Three-piece set	4 25 to 5 75	5 75 to 14.50	1 75 to 2 50	4 50 to 6 00	7 125	12 25	2 567	1.305
Per cubic foot	0 36 to 0 48	0 48 to 0 66	0 12 to 0 20	0 32 to 0 50	0 58	0.73	0 209	0 078
Bituminous coal mines (Pa.):								
Squared timber, 8 to 12 in.:								
Three-piece set	4 25 to 5 75	7 60 to 14 50	1 20 to 2 40	....	6 80	12 85	2 450	1 369
Per cubic foot.	0 36 to 0 48	0 54 to 0 66	0 10 to 0 20	....	0.57	0.75	0.205	0 080
Anthracite coal mines (Pa.):								
Loblolly pine, 12 in. diam.:								
Three-piece set	5 10 to 8.50	10 50 to 13 50	6 40	9 15	13 20	18 40	4 757	1 960
Per cubic foot	0 24 to 0 40	0 42 to 0 48	0 36	0 43	0 68	0 81	0 245	0 086

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* The cost in place was determined by adding the average labor cost of installation to the average of the untreated and treated timber costs, respectively.

† Based on 4 per cent interest (see Table XVII) and an average life of 3 years for untreated and 12 years for treated timbers.

buildings and other surface structures as well as for miscellaneous mine and mill equipment, including mine cars and trucks, concentration tables, flotation machines, and the like. It has been estimated that 80 per cent or more of the repairs and replacements required by these structures and equipment are the result of decay, and could be largely avoided by the use of treated timber. When untreated timber is used under conditions favoring decay, its average life in surface structures is estimated to be from 10 to 12 years and in mine and mill equipment from 6 to 8 years. Based on an average period of usefulness of 20 years for all kinds of mine construction, timber subjected to decay in the surface structures will require replacement at least once, and that in mine and mill equipment at least twice. The original use of adequately treated material would thus eliminate the labor and material costs involved in such maintenance. (12.)

INFLUENCE OF PRESERVATIVE TREATMENT ON WOOD MARKETS

The preservative treatment of wood has played a significant role in helping to maintain the demand for various structural timber products, in the face of marked improvements in the design and use of competitive materials. In the 27 years from 1909 to 1935, inclusive, a total of approximately 5¼ billion cubic feet of wood was treated, or an average of over 194 million cubic feet per year. Had the consumers of this material found it necessary to use untreated timber to fill their needs, their annual wood requirements would soon have been increased from two- to four-fold. Such an increased consumption of wood products, while temporarily beneficial to the timber producers, would have had the inevitable effect of causing an accelerated depletion of a relatively few favored species and led to higher initial costs and increased annual charges for the wood products concerned. The ultimate result of such an unsatisfactory economic situation for the consumers would have been a general loss in wood markets through the extensive substitution of other structural materials. The railways have saved hundreds of millions of dollars in operating expenses through the lower annual charges of treated wood as compared with the yearly costs of the steel and concrete products that might have been used in its place. The same financial benefits have accrued, although in smaller degree, to other public utilities, to government agencies, and to general consumers of treated timber in large quantities.

The widespread substitution of steel and concrete for the structural wood products under consideration would have been disastrous to the timber industries concerned, causing a general stagnation in the production of the affected products and forcing prices so low as to remove any real incentive to grow such timber for profit. Poles, posts, piles, ties, mine timbers, and most of the other products generally treated today, can be made from relatively small trees. Hence, the existence of a large market for such products makes it possible to harvest timber profitably on a short rotation, without waiting for it to grow to saw-log size. The demand for these treated items also promotes wood utilization in certain regions where tree growth is slow and much of the timber may never attain saw-log size. Lodgepole pine in the Rocky Mountains affords a conspicuous example of this particular situation. Furthermore, many of the wood products generally treated are not particularly restricted as to the presence of knots and other defects and can be manufactured from timber that would not make high-grade lumber. Because of this fact, operators are able to dispose advantageously of some of the lower-grade material that must necessarily be produced in sawing logs for lumber and, in this way, to reduce the net cost of producing the lumber.

A large proportion of the total annual supply of ties, posts, poles, piles, and mine timbers is obtained from farmers and other small operators, working with practically no capital and but little equipment. By helping to maintain the market for these products, the wood-preserving industry has been largely instrumental in furnishing gainful employment for thousands of individual woods workers as well as providing a cash income from many farm woodlots.

In short, the preservative treatment of wood has not only served to reduce the operating costs of the consuming industries but has been of distinct benefit to the timber producers themselves. By extending the service life of naturally nondurable species and sapwood timbers, wood preservation has made it possible to shorten crop rotations and avoid the serious depletion of a few previously favored species. And, by maintaining the market for structural wood products, it has provided employment and income for small woodland owners and woods workers, as well as large operators, and also encouraged the growing of timber for commercial purposes. The general economic advantage of timber preservation to the nation as a whole is obvious.

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CHAPTER IX

PROPERTIES OF TREATED WOOD

Inasmuch as the primary purpose of applying preservatives to wood is to increase its normal resistance to decay, termites, marine borers, and other deteriotating organisms, it is but natural that the greatest importance should be attached to the permanence of the treated material and the resultant economy in its use. However, it is often also necessary to consider the effects that the introduction of oils and water-soluble salts may have on other significant properties of wood. As the use of treated wood has been extended into more diversified fields, increased importance has been attached to certain of these effects, and considerable attention has been given to devising ways and means of preventing or overcoming deleterious influences on the natural strength, inflammability, painting characteristics, cleanliness, weight, or electrical conductivity of the timber, and of obviating other objectionable characteristics which the preservatives may impart to the wood.

STRENGTH

Since treated wood must usually meet rather definite strength requirements, it is essential that neither the preservative nor the methods of preparation and treatment employed reduce the load-carrying capacity of the timber below acceptable limits. Numerous investigations have been made to determine the effects of standard preservatives, conditioning treatments, and pressure processes on the strength of wood. These tests indicate that any resultant weakening of timber is caused almost entirely by the temperatures and pressures to which the wood is subjected during the conditioning or impregnation period rather than by the preservative used (20, 32). The several creosotes and creosote mixtures (with coal tar or petroleum) are practically inert to wood, entering into no chemical reaction that would affect its strength. Zinc chloride, in the 2 to 5 per cent solutions used in commercial practice, is also virtually inactive, although it apparently makes wood somewhat brittle under impact (21). In high concentrations, however, this salt may seriously weaken wood, and even moderate absorptions may prove harmful when treated timber is exposed for a considerable period of time to low atmospheric humidity and high temperature. Thus, zinc-chloride-treated railway ties installed in arid regions have been found to check and splinter worse than untreated or oil-treated ties, apparently because the salt solution in the wood became highly concentrated under the influence of the heat and dryness (3).

EFFECT OF TREATMENT

Although the standard preservatives are not normally considered harmful in themselves, the procedure followed in applying them to wood may be so severe as to cause considerable reduction in the strength of the timber. The steaming-and-vacuum treatment may have a particularly marked weakening effect, unless the temperatures employed are carefully adjusted to the kind of timber involved. Thus, while a steam pressure of 20 lb. may be applied to southern pine with little evidence of injury, such a treatment is entirely too severe for hardwoods and certain softwood species, such as Douglas fir. Short steaming periods at lower pressures (page 167) may not be harmful to these sensitive woods, however. Under normal conditions, the boiling-under-vacuum (Boulton) process is less likely to weaken the timber seriously than the steaming-and-vacuum method. But, even when these conditioning steps are omitted, the strength of the timber may be definitely impaired during the actual impregnation period, unless the temperature and pressure to which the wood is subjected are properly controlled.

In considering the effect of impregnation methods on the strength of wood, it is well to remember that the decay resistance imparted by good preservative treatment is of definite advantage in relation to design stresses. The U.S. Forest Products Laboratory recommends (34) that, in designing structures of untreated wood, considerably lower working stresses be employed for extreme fiber in bending, and for compression perpendicular and parallel to the grain, when conditions of use favor decay than when there is no decay hazard. Suitable preservative treatment avoids the necessity of reducing working stresses, in order to discount early decay.

In the steaming-and-vacuum treatment, the extent to which the wood is weakened is influenced not only by the temperature and duration of the steaming period but also by the species, size, and condition of the timber involved. Somewhat variable results have been obtained from strength tests on wood conditioned by this method, but it has been demonstrated that steaming at high temperatures or for long periods definitely reduces the strength of the timber (15, 16, 33); in extreme cases, the loss in fiber stress at maximum load was as high as 35 per cent (5), and the reduction in certain other strength properties occasionally exceeded 50 per cent (16). Large timbers are weakened to a greater degree than small ones, possibly because of the more severe internal stresses developed in the more sizable pieces. Also, heartwood is apparently more susceptible to injury than sapwood. For this latter reason, round timbers, such as poles and piles, especially those which have a thick sapwood, are less likely to be severely damaged

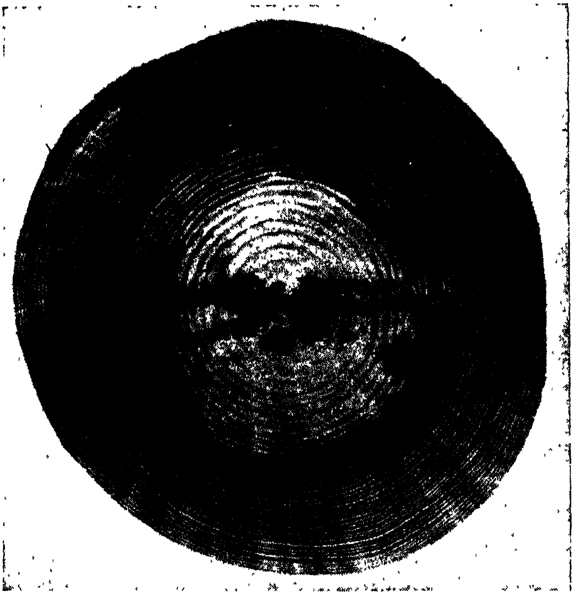

FIG. 72.—Burst checks (ring shakes) in southern pine pole, probably caused by excessive pressure and heat. Note also radial crack through center. (*U.S. Forest Products Laboratory.*)

under a given treatment than otherwise comparable sawed sticks having exposed heartwood faces. Koehler (22) has shown that heating green wood in steam sets up severe stresses due to the tendency of the wood to expand tangentially and shrink radially under such conditions. These stresses may be of sufficient intensity to cause radial cracks through the center and ring shakes, or "burst checks," near the circumference of round timbers (Fig. 72). Mild hydrolysis, catalyzed by the natural acids in the wood, is very probably a factor in the weakening of timber by steaming. Cellulose is especially subject to this hydrolytic action, being gradually decomposed into various degradation products of low molecular weight. Different species of wood vary considerably in natural acidity, and this may have a direct bearing on their sensitiveness to injury by steaming or other form of heating.

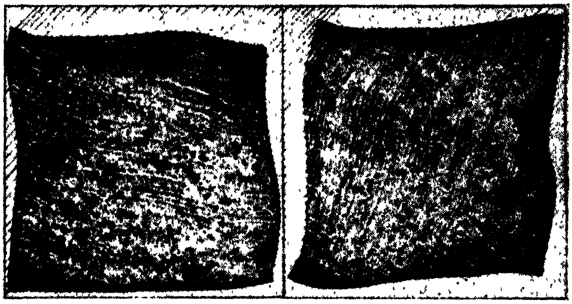

FIG. 73.—Severe collapse, caused by too much pressure while the wood was hot and soft. (*U.S. Forest Products Laboratory.*)

There may be considerable loss in strength, moreover, without visible damage. Thus, wood that shows no signs of injury immediately following the steaming-and-vacuum treatment may reveal serious checking and collapse (Fig. 73) after the subsequent preservative pressure period, thus indicating that it was at least temporarily weakened by the steaming. Also, wood may appear perfectly sound after all treating operations have been completed and yet be appreciably weakened. According to MacLean (24), experiments on several different softwoods have indicated that, during the actual impregnation of preservatives, there was less checking and collapse in wood that was steamed while green than in that which was air seasoned prior to the steaming treatment. However, the oaks and certain other woods usually check severely even when the timber has a high moisture content at the time of steaming. The greatest decrease in strength is found when timber is tested soon after being steam conditioned, for part of the loss is regained as the wood seasons after treatment. However, the effect of treatment on any one strength property varies so much for individual timbers that it is not possible to say just how much recovery may be expected.

It is believed that any steaming conditions severe enough to have a noticeably beneficial effect on the subsequent penetration and absorption of preservative will cause some reduction in strength. However, it is generally considered that the effect of steaming at a pressure of not over 20 lb. (259°F.) for not more than 8 to 12 hr. may be ignored in southern pine poles, piles, and large structural items that are not required to have the highest possible strength. On the other hand, if the timbers are to be placed in a structure in which no weakening due to treatment can be tolerated, they should be air seasoned rather than steamed, prior to impregnation.

Numerous strength tests have been made on Douglas fir timbers to determine the effect of the boiling-under-vacuum treatment (13, 14, 25, 26, 33). In general, it was found that the loss in bending strength, resulting from this method of conditioning and the subsequent impregnation of creosote, varied from about 6 to 18 per cent. The degree of weakening was apparently correlated with the length of the heating period. Because of the comparatively low temperatures to which the timber is subjected in this process, the loss in strength is much less than when Douglas fir is steamed at high temperatures (33) and is not a cause for concern in most uses to which the treated timber will be put. However, these tests show the desirability of keeping the treating conditions as mild as is consistent with adequate absorption and penetration of creosote.

In the actual impregnation of wood with a preservative (preservative pressure period), the most important factors to be considered are the intensity of the pressure employed and the duration of the pressure period. The extent to which the preservative is heated also has a definite bearing on the problem, but, since this feature has a significant effect on the penetration and absorption obtained, it is usually desirable to maintain relatively high temperatures. Consequently, when the specified combination of pressure and temperature is likely to cause the wood to check or collapse, it is advisable to lower the pressure rather than the temperature and, if necessary, to lengthen the impregnation period.

The precise effect of any combination of preservative pressure and temperature will depend, in turn, upon such factors as the species, character, and previous treatment of the timber involved and the type of preservative used. Woods of low density are more subject to injury from high pressure than those of high density. Considerably higher pressures can be used with safety on timber that has been heated for a short time only, or not at all, than on material that has been softened by long preliminary heating. Under the same treating conditions, timbers impregnated with water-soluble salts exhibit a greater tendency to collapse than similar material treated with preservative oils, probably because the water solutions tend to soften the wood more than the oils (24). (For more detailed discussion of pressure and temperature effects, see Chap. VII.)

EFFECT OF INCISING

The incising of sawed Douglas fir products, cedar pole butts, and certain other woods used for crossties results in some reduction in strength, but the disadvantage of this loss, as a rule, is more than offset by the increase in protection resulting from the improved absorption and greater uniformity of penetration of preservative (Fig. 66). For example, although an incised pole may be somewhat weaker than an unincised one when first placed in line, because of its superior treatment it should be much less affected by decay in service, and, after a few years, its strength should average higher than that of the unincised pole. The same generalization holds for sawed material.

Although strength tests have been made on incised Douglas fir from time to time (13, 14, 25, 26), there is a lack of agreement as to the extent to which this practice weakens the timber. The engineers at the U.S. Forest Products Laboratory believe that the percentage loss in bending strength produced by incising is roughly approximate to twice the percentage reduction in section modulus at a cross section through a maximum number of incisions.

RETENTION OF STRENGTH

One of the most significant characteristics of adequately treated wood is the extent to which it retains its strength when placed in service under conditions that lead to the gradual, or often rapid, deterioration of untreated timbers. Numerous reports have been made on treated poles, piles, and general construction timbers that have not been subjected to pronounced mechanical wear and that have maintained their load-carrying capacities for many years—often even longer than the useful life of the structures in which they were incorporated. Actual tests of creosoted timber removed from the railroad trestle across Lake Pontchartrain showed that, after 45 years of service, the strength of the material compared favorably with that of new, untreated wood (12). In bridges, trestles, wharves, paved street-railway track, urban pole lines, and other wooden structures designed for long-time service and in which replacements are both difficult and costly to make, reliance on the continued strength of treated wood also leads to a marked reduction in inspection and maintenance costs.

The retention of strength in treated wood is often so marked as to give the timbers definite salvage value, when the structures of which they form a part become obsolete. As indicated in Chap. VIII, there are numerous records of treated timbers which, having outlived the usefulness of the structure in which they were originally incorporated, have been used again in remodeling the old structure or in building a new one.

INFLAMMABILITY

The effect of preservatives on the inflammability of wood is important in certain forms of construction. This is true, for example, in wharves, bridges, trestles, open timber foundations, shafts and other timbered mine workings, and even in highway culverts, pole lines, and highway and fence posts. For structures where serious fires may entail heavy replacement charges, or even lead to loss of life, the presumed fire hazard may be a decisive factor in the choice between treated and untreated wood or among timbers impregnated with different preservatives.

From the point of view of their effect on the inflammability of wood, zinc chloride and other salts are acknowledged to have a general advantage over the preservative oils. In fact, the promoters of certain water-soluble proprietary preservatives make definite claims of fire resistance for their products. When injected in the usual quantity (about ½ to 1 lb. of dry salt per cubic foot of wood), zinc chloride has a slight effect in reducing the inflammability of timber; in greater quantities (4 lb. or more per cubic foot), the increase in resistance to the spread of fire is very marked (19). Concentrated zinc chloride solutions may seriously damage wood, however, so that the absorptions required to give high fire resistance are not safe to use in load-carrying members of structures. The effectiveness of other water-borne preservatives is probably more or less similar to that of zinc chloride, but the fire resistance provided by the low absorptions commonly used for decay- and insect-prevention is insignificant.

In contrast to zinc-chloride-treated material, creosoted timber is sometimes objected to because of the supposed fire hazard involved in its use. Unquestionably, freshly creosoted wood can be ignited easily, and the oil on its surface burns freely, producing a dense smoke. In recognition of this condition, sand or dry cement is sometimes spread over the upper surface of freshly treated highway bridge floors, open-deck railway bridge ties, and other structural material that is so placed as to make this method of protection practicable. After the treated timber has been seasoned for a few months, however, the more volatile, and hence more inflammable, fractions of the oil disappear from the surface, and there is reason to believe that creosoted wood is then no more easily ignited than sound untreated timber. Unfortunately, there is some contradictory evidence on this point, and engineers have not been able to agree as to the extent to which cresosoted wood should be regarded as a fire hazard. In view of this situation, the use of preservative oils can hardly be recommended for treating timber that is to be installed in structures in which fire resistance is considered of utmost importance, unless the treated wood is to be covered with a fireproof coating or otherwise protected against combustion. However, it should be emphasized that the danger from improper construction and maintenance may far exceed that arising from the use of creosoted wood.

One point that should be stressed in connection with this discussion is that the comparison has been drawn between creosoted timber and *sound* untreated wood. It is a well-recognized fact that, after untreated material has started to decay, it takes fire more readily than wood that has been kept sound by a preservative. This is particularly evident in dry locations, where partly decayed wood may be easily ignited by a small spark that would have no effect on the surface of sound timber. Under such circumstances, it is the untreated timber and not the creosoted material that affords the greater fire hazard.

It has been observed that, except under conditions which strongly favor continued combustion, such as exposure to high winds or continued contact with other flaming materials, creosoted timbers of moderate to large size do not keep on burning for prolonged periods of time; nor are they usually seriously damaged, beyond being charred to a relatively slight depth (17, 29). This has been demonstrated repeatedly in connection with the periodic burning of rights of way, where serious grass fires, which have definitely weakened untreated poles and posts, have failed to impair the general serviceability of creosoted timbers. Most engineers who have had extensive experience with creosoted timber in pole lines, bridges, trestles, wharves, water tanks, and other structures seem to regard the economy resulting from the use of the treated wood as far more significant than any questionable fire hazard that may be involved.

PAINTING CHARACTERISTICS

In general, wood impregnated with preservatives is used under conditions that do not require the application of paint for either decorative or protective purposes. There are, however, certain instances in which it is highly desirable, or even essential, for the treated material to receive and retain a suitable coating of paint. Such is the case with highway posts and guard rails as well as certain poles and bridge timbers located along highways, which must be made readily visible with white or other light-colored paint, in order to safeguard motorists, especially at night. The roof timbers and ceiling boards in textile and paper mills, canning factories, and similar buildings, are often impregnated with preservatives before installation because of the marked decay hazard occasioned by the high atmospheric humidities and favorable temperatures which prevail within these structures; in such cases as these, the application of a light-colored paint serves to improve the interior illumination as well as to enhance the appearance of the buildings. Furthermore, treated lumber used in porches and other exposed parts of residences may need to be painted for decorative reasons and also for protection against weathering.

CREOSOTED WOOD

No completely satisfactory method has yet been devised for covering creosoted wood with light-colored oil paints, since the preservative, being miscible with the drying oils in such paints, causes a rapid discoloration of the coatings (6, 10, 11). However, the rather recent development of aluminum paints, made by mixing aluminum powder with a special bodied oil or other suitable vehicle, has afforded a partial solution to the problem. Two coats of a good aluminum paint provide a very durable coating, which, while not entirely immune to discoloration by the creosote, stains less frequently and less seriously than other paints. White or other light-colored coatings cannot safely be applied over the aluminum paint, however, for they are very likely to become stained even though the aluminum is not.

Even with the aluminum paints, certain precautions must be taken to insure satisfactory service. Freshly creosoted timber should be allowed to season for a period of several weeks before the paint is applied, in order that the highly volatile constituents of the oil may evaporate from the surface layers of the wood. Furthermore, the treatment should be such as to reduce to a minimum the tendency of the oil to exude on the surface, or *bleed.* Thus, timber impregnated with moderate amounts of creosote by an empty-cell process can generally be painted more successfully than that treated by the full-cell method or with high absorptions (23); likewise, straight creosote treatments are preferable to those in which creosote-tar solutions are used. However, the beneficial effect of the empty-cell treatment in retarding bleeding is limited largely to round timbers or to the sapwood surfaces of sawed material.

With regard to securing adequate visibility for creosoted timbers that are placed along highways, other means than direct painting may be found practicable. To this end, some public utility companies have used untreated wooden battens or slats, or sections of the lath-wire type of "snow fence," which were painted and fastened vertically around creosoted poles. In other cases, bands of metal, painted white, have been fastened around creosoted highway posts. These methods have not yet been generally adopted, however, owing to the cost of installing and maintaining the painted battens or metal, but it is probable that their use will increase. Another method, which appears to have some merit, involves the installation of buttons or other types of reflectors on the creosoted timbers.

ZINC-CHLORIDE-TREATED WOOD

The painting of timber that has been impregnated with zinc chloride is a relatively simple problem, if the wood has first been adequately dried. Under ordinary circumstances, discoloration of the paint is not a factor, since water-soluble preservatives are generally incapable of diffusing into the drying oils. Furthermore, the coatings can be maintained at reasonable cost, although, for exterior use, the ordinary linseed-oil paints are somewhat less durable than on untreated wood. (6, 11.)

It has been found (6) that a priming coat of aluminum paint greatly increases the durability of ordinary white paint on zinc-treated wood. The use of such a priming coat is considered particularly advisable on southern pine, Douglas fir, and other woods that have pronounced bands of dense summer wood. Attention is called to the fact that two applications of white paint will usually be required, since it is very difficult to hide the aluminum satisfactorily with a single coating. Browne (6) also found that paint lasted fully as long on timber treated with a mixture of two parts of zinc chloride and one part of sodium dichromate by weight as it did on comparable untreated wood.

So far as is known, wood treated with Wolman salts, Z.M.A., and probably other proprietary preservatives, can be painted as satisfactorily and durably as wood treated with zinc chloride or chromated zinc chloride.

BLEEDING OF CREOSOTED WOOD

Difficulty is sometimes experienced with timber impregnated with creosote or cresosote mixtures, because of the exudation and accumulation of preservative oil on the surface of the wood while it is in use, or even during storage. In extreme cases, the oil may drip from the wood or run down the surface and collect at the base of upright timbers. With some products, such as foundation piles and crossties, this so-called "bleeding" is of little or no consequence, inasmuch as it is not likely to affect the service life of the wood to any measurable degree and does not cause any inconvenience after the timber has been installed. But, in certain other products, it may be the source of much trouble and annoyance and may even tend to discourage the use of creosoted wood. This is particularly the case with pressure-treated poles, since the oily exudate is objectionable to linemen climbing the timbers and, in urban sections, to pedestrians and others coming in contact with it. It must not be assumed from this that all creosoted products will develop this objectionable condition. Vast numbers of pressure-creosoted timbers are being used with complete satisfaction, even under conditions that favor the exudation of the preservative.

The factors responsible for bleeding have not been fully established, but the immediate cause is considered to be the heating of the exterior of the treated wood by solar radiation. The dark color of creosoted timber causes it to absorb considerable heat from the sun's rays; temperatures in excess of 140°F. have been measured on the surface of creosoted posts lying on the ground in bright sunlight, while on standing posts the surface temperature on the sunny side has been found to be from 12 to 24°F. higher than that on the shaded side (31). The air and preservative in the heated outer layer of wood expand, causing the oil to flow toward the surface of the timber. That the intensity of exposure to sunlight is a factor of paramount importance is indicated by the common observation that bleeding is generally confined to the surface facing the sun; it has also been noted that the exudation tends to stop as soon as the sun becomes obscured (30). Poles and posts lying on the ground receive more direct sunlight and attain higher surface temperatures than when they are erected (31); consequently, they may bleed more before being placed in service than when standing in line (30). Furthermore, bleeding is most prevalent in the summer months, although it may occur during the winter. While the exudation of preservative is heaviest during the first year after treatment, it has been found to occur periodically for several years on some pole installations.

Other factors besides the surface temperature of the treated timber are recognized as having an influence on bleeding. It has been indicated (1, 24, 28, 31) that the exudation of preservative is dependent to some extent upon the character of the oil used, the amount injected into the wood, the method of impregnation, and the nature of the timber itself. Straight coal-tar creosote is less likely to be objectionable than mixtures of creosote and coal tar or creosote and petroleum. Similarly, among the straight creosotes themselves, the lower boiling preservatives are considered to be less troublesome than high-boiling oils or those that have a high residue above 355°C. It has been suggested, however, that the observed variations in bleeding in these cases may be apparent rather than real, owing to differences in the extent of evaporation of the exudates (7, 24). For example, even though the amount of bleeding was approximately the same, a preservative of low volatility would tend to show greater surface accumulation than one of higher volatility, since a smaller proportion of the former would evaporate on exposure to the air. It is, of course, the more permanent surface accumulation that is most objectionable. The depth of color imparted to the treated wood by the preservative is also considered to be a contributing factor to the bleeding of the oil, although it cannot be disassociated in its effects from such other preservative features as viscosity and residue. When test poles were exposed to bright sunlight, higher surface temperatures were recorded, and more apparent bleeding was noted on black timbers than on brown ones (31). Similar observations with regard to the relation of color to extent of bleeding have been made on both poles and posts in actual service.

The amount of preservative injected into wood under a given process may affect the subsequent exudation of oil, at least to the extent that timbers with relatively low net absorptions are less likely to bleed than those which retain larger quantities of preservative without receiving a proportionate increase in depth of penetration. Furthermore, the general method of impregnating the wood is also an apparent factor, for tests have shown that poles treated by a full-cell process bleed more than similar timbers that have been given an empty-cell treatment; this condition was found to exist even when the empty-cell process gave somewhat higher retentions than the full-cell method. (31.) In any event, the incidence and intensity of bleeding appear to be dependent upon the concentration of preservative in the outer part of the wood; when this is high, the oil more nearly fills the voids (cell cavities) in the exterior layers, and there is less room for expansion of preservative within the cells when it is heated.

The character of the timber, especially as it relates to the resistance that the wood offers to impregnation, may be a significant factor. While sapwood and easily treated heartwood may exude creosote to a marked degree, refractory heartwood appears to be definitely more subject to bleeding. The distinction is apt to be particularly noticeable on timbers that have mixed sapwood and heartwood faces. Here, again, the extent to which the oil exudes is apparently dependent upon the depth of penetration, at least in so far as it affects the concentration of preservative in the outer layers of the wood. A study (7) of southern pine poles, which were steam conditioned and impregnated with creosote by the Rueping process, indicated that the relative amount and distribution of summer wood in the sapwood layer may have a definite influence on the bleeding of such timbers. In most growth rings, the amount of air space present in the summer wood after treatment was found to be appreciably less than that in the spring wood, so that the expansion of the preservative would tend to result in more pronounced exudation of oil from the denser portion of the growth ring. Consequently, it has been suggested that poles having a high proportion of summer wood, either in the sapwood as a whole or in its outer layers, might be expected to bleed more than comparable timbers with relatively small amounts of summer wood.

While the exudation of preservatives may be reduced by controlling the contributing treatment factors, it may not be completely eliminated, and the producer of creosoted timber is unable safely to guarantee that his product will be entirely free from bleeding. A number of variations in normal empty-cell treatments have been devised in an attempt to reduce the tendency of creosoted wood to bleed (24). In some cases, the timber is subjected to an *expansion bath* upon completion of the preservative pressure period, in order to remove part of the air and surplus preservative. This step consists in raising the temperature of the oil in which the timber is still submerged, from 10 to 20°F. above that maintained during the pressure period. After a sufficient heating period, which is usually limited to a maximum of 2 hr. in Douglas fir treatments, the preservative is drained from the cylinder, and the customary empty-cell final vacuum is applied. The amount of air and free oil in the surface layers of the timbers is sometimes reduced by following the preservative pressure period with a *final steam bath*. After the creosote has been drained from the cylinder, the charge is steamed before the final vacuum is applied. The steam pressure within the cylinder is built up to 15 to 20 lb. and held for 15 min. or longer. Still a third method, used at a few plants, involves the application of a *final air pressure* after the preservative has been withdrawn from the cylinder. This is intended to force the free oil deeper into the wood. Air pressures up to 150 lb. or more are held for periods of from 3 to 4 hr.

At least two processes have been designed to control bleeding in poles by the addition of suitable materials to the creosote. Vaughan (28) recommends the addition of 0.5 to 2.0 per cent of lecithin, a vegetable phosphatide from soybeans, which is claimed to have a very favorable effect upon the viscosity and surface tension of the oil and upon the color of the treated wood, thus producing poles that are practically nonbleeding. Coolidge (8) patented a method for adding montan wax to creosote (U.S. pat. 1,556, 570, Oct. 6, 1925) in such proportion that the mixture would solidify upon cooling and remain in solid form even at the temperatures attained at the surface of poles exposed to full sunlight (about 140°F.). This required about 60 per cent of wax in the mixture. A similar result was accomplished by treating timber first with creosote and then with montan wax. The montan treatments did not become popular, partly because of their high cost and partly because of doubt as to their long-time effectiveness against both decay and bleeding.

DISCOLORING EFFECTS

Some difficulty has been encountered in dwellings and similar buildings, as the result of the discoloration of finished lumber that was nailed directly to creosoted material. In such cases, the creosote may creep along the nails and stain the exposed wood surface at the nail heads. This trouble may be avoided by blind nailing or by the use of untreated nailing strips. In the latter case, the finish lumber is fastened to the strips in such a way that the nails do not reach the treated wood. It is also considered inadvisable to apply plaster over creosoted wood unless the treated material is covered with a waterproof paper, and metal lath is used for the plaster base. When wood lath is nailed to creosoted studding, the plaster may absorb such oil as moves along the nails and become stained in spots. (18.)

CORROSIVE EFFECTS

The obviously corrosive chemicals find little or no use as wood preservatives in this country, being rejected chiefly because of the extent to which they would depreciate treating equipment. Consequently, it is not necessary to consider the possible deterioration of metal fittings and fastenings that might be attached to wood treated with these substances. However, the question is sometimes raised as to the long-time corrosive action of the acceptable preservatives upon railroad spikes, bolts, nails, staples, screws, and the like. Study and experience have afforded rather definite knowledge as to the effects of creosote and zinc chloride, but there is a dearth of impartial information about most of the other preservatives in use today.

With the possible exception of certain wood-tar derivatives, the creosotes and allied preservative oils are acknowledged to have practically no corrosive effect on metal. On the other hand, tests (32) have demonstrated that zinc chloride (2.4 per cent solution) has a definite corrosive action on flange steel. As is the case with toxicity determinations, however, the conditions surrounding such laboratory investigations on treating solutions are not directly comparable with those encountered in actual service. Thus, while these tests are useful for general comparisons and give definite results in relatively short periods of time, they do not afford conclusive evidence of the corrosion of actual fastenings or fittings, when these are attached to commercial forms of treated wood and exposed for long periods of time under widely varying conditions of service.

An investigation was begun at the U.S. Forest Products Laboratory in 1928 to determine the extent to which steel, brass, and galvanized-iron fastenings corrode when inserted in zinc-chloride-treated wood and subsequently subjected to outdoor conditions and to different degrees of interior humidity. When the fastenings were examined, at the end of a 5-year period, it was found that those of brass and galvanized iron were but slightly corroded, even when exposed to high humidity. The wire nails, on the other hand, were so badly deteriorated under extremely humid conditions that their use is considered inadvisable when the zinc-treated wood is to be placed in very damp situations. However, in moderately humid interiors or under outdoor conditions such as prevail at Madison, Wis., the corrosion of these steel fastenings in treated wood does not appear to be appreciably greater than in comparable untreated material, provided that the treated wood has been seasoned before the nails are driven. The necessity for properly seasoning timber after impregnation was indicated by the observation that nails driven into wet treated wood, which was placed under conditions that caused it to lose moisture, were subject to rapid corrosion during the drying period. It was further noted that the corrosion of wire nails was not materially affected by painting the zinc-treated wood, nor was it reduced to any notable degree when sodium dichromate was added to the treating solution. (2.) The general suitability of steel fastenings for use with zinc-treated lumber, fence posts, and other products has been fully demonstrated by actual service under outdoor conditions. Wire nails and staples were found to be in good condition after 12 to 15 years of service under such diversified climatic conditions as prevail at Carbondale, Ill., and Somerville, Tex. (9).

Much of the available information on the subject pertains to the corrosion of railroad spikes when inserted in ties treated with zinc chloride. While the data are somewhat conflicting, it is concluded (20) that, in general, the deterioration is not particularly serious. There is also evidence that corrosion of spikes may be caused by other factors than the preservative in the wood. Brine dripping from refrigerator cars, electrolysis in connection with signal systems, and the acid character of cinder ballast have been suggested as possible causes of excessive corrosion of spikes and other metal fastenings.

ELECTRICAL RESISTANCE

The fact that dry wood offers such marked resistance to the passage of an electric current as to be classed as a nonconductor, at least for low voltages, is a definite advantage for certain uses of timber. This resistance varies somewhat in different species of wood; is greater across than along the grain; and is affected by changes in temperature, approximately doubling with each decrease of 22.5°F. But the most significant variation is that which accompanies changes in moisture content; as any given piece of wood dries from the fiber-saturation point to the oven-dry condition, the resistance increases about a millionfold.

It is evident that the presence of a preservative in the wood may also influence its electrical resistance, and various investigations have been made to determine this point. In general, it has been found that creosote does not have a definite effect upon the natural resistance of wood (20, 27). When a creosoted timber is discovered to have a low resistance, the condition may usually be attributed to a relatively high moisture content of the wood; such is often the case with pine poles inadequately seasoned prior to the impregnation of the preservative (27). On the other hand, the injection of zinc chloride or other water-soluble salts may materially reduce the electrical resistance of the wood.

Studies of the effect of zinc chloride have centered largely around crossties that were placed in track in the vicinity of automatic block signals, since the greatest difficulty is experienced at these points, due to the leakage of current both between the rails themselves and between the rails and moist ballast. It has been determined (20) that the reduction in electrical resistance is appreciable in freshly treated ties, the extent of the decrease depending upon the amount of salt injected. However, the effect is greatly influenced by the amount of moisture in the wood and diminishes notably as the treated ties season; after a few months to a year it ceases to be serious. In view of this condition, it has been recommended that zinc-treated ties be seasoned for 2 to 6 months before being placed in a circuited track. It has also been suggested that the number of such ties installed each year in any track circuit should not exceed 15 per cent of the total number of ties in that circuit.

MISCELLANEOUS EFFECTS

The more thorough preservative treatments may add materially to the *weight* of wood, the precise effects depending upon the absorptions obtained and, in the case of water-soluble salts, upon the extent to which the wood is seasoned after treatment. In pressure treatments with preservative oils, net retentions (weight increases) of as low as 5 lb. or as high as 20 lb. or more per cubic foot of wood may be secured. For the bulk of material so treated, a range of 6 to 12 lb. is most prevalent. With these more usual absorptions, the oil-impregnated timber will probably have about the same approximate weight as green, untreated material of the same kind of wood. The hot-and-cold-bath treatment with creosote may add 4 to 6 lb. per cubic foot to the weight of the wood; but in most cases, and especially with refractory species, the absorptions will be appreciably less. Products treated in this way will usually be lighter than comparable untreated timbers that have not been peeled or seasoned.

The impregnation of timber with zinc chloride and other waterborne preservatives increases its weight immediately after treatment much more than the injection of creosote, because of the large quantity of water that is forced into the wood. The actual increase naturally depends upon the character, species, and condition of the wood. The weight of very dry material, with a high percentage of sapwood, may be doubled by the treatment; while in timber that is not well seasoned or that has only a narrow sapwood, the increase may be less than 30 per cent. For example, an absorption of ½ lb. of dry salt per cubic foot could be obtained in easily treated sapwood by injecting about 33 lb. of a 1½ per cent solution, while in wood that is difficult to penetrate the same absorption might be secured by introducing 10 lb. of a 5 per cent solution. When the wood is subsequently seasoned, most of the injected water evaporates, and in time the weight per cubic foot may be reduced to within approximately a pound of what it was before treatment. Seasoning before use is a necessary step if the timber is required to maintain its general size and shape when placed in service, since loss of moisture below the fiber-saturation point will cause the wood to shrink. Most products are air seasoned, when it is necessary or desirable to dry the material before use. In fact, with moderate- to large-size timbers this is the only practicable method of reducing the moisture content. In the case of lumber, however, it is possible to kiln dry the treated wood satisfactorily; with proper equipment, 1-in. southern pine can be dried to approximately 12 per cent moisture content in about 2½ days, while 2-in. lumber requires 4 or 5 days to reach the same degree of dryness (1). It is claimed that the cost of kiln drying or air seasoning is often more than offset by the saving in freight charges resulting from the reduction in the weight of the treated wood.

Objection is sometimes voiced to the *odor* of creosoted wood, especially in dwellings and other occupied buildings where the treated material is used for sills, floor joists, subfloors, floor-nailing strips, and similar purposes. The odor is most noticeable when creosoted wood is installed in inadequately ventilated basements or other enclosed spaces, or when buildings containing treated timber have been closed for some time. However, even when the odor is strong enough to be noticeable, it generally disappears within a few months. It is considered entirely practicable to use creosoted wood for the above-mentioned purposes in residences and other buildings up to and including the first floor (Fig. 6), provided reasonable precautions are taken. The use of heavily treated material is to be avoided, although absorptions as high as 8 lb. per cubic foot, injected by an empty-cell process, can apparently be used without trouble. It is stated, however, that the surface accumulation of creosote on wood that has recently been sprayed, brushed, or dipped gives rise to more objectionable odors than are noted in material treated by the empty-cell method. All creosoted wood should be air seasoned sufficiently to dry the surface before it is installed. Furthermore, unless it is adequately insulated, the treated material should not be placed close to furnaces or hot pipes, or in other locations where it may be heated to such a degree that creosote fumes will be freely liberated. It is also imperative that heating, cooling, or ventilating air should not be circulated through enclosed spaces containing the odors of creosoted wood. In basements, any objectionable odor may be masked by applying untreated wood, wall board, or similar sheathing over the treated material. (18.) Creosoted wood should not be used where its odor can contaminate sensitive foods, such as butter and flour, because the taste of the food may be noticeably affected.

The *fumes* of creosote in confined spaces may destroy or injure tender plants. Hence it is unsafe to use creosoted wood in greenhouses. The fumes will be especially harmful if the creosoted wood is placed near heated pipes. Damage has also resulted in greenhouses from bench boards treated with mercuric chloride. Other volatile or leachable preservatives could also be injurious if sufficiently concentrated in the soil or the air. When used outdoors near plants, creosote seems to have little if any effect. While it would doubtless be unsafe to place a valuable plant in direct contact with a heavily creosoted pole or post, or in a place where creosote bleeding from the wood could come into direct contact with it, common experience indicates that the effect of the creosoted wood does not extend any appreciable distance into the soil.

It has been reported that perpendicularly driven nails do not hold so well in creosoted timber as they do in untreated wood. Diagonal nailing is said to result in better *nail-holding ability* in the creosoted material. It is recommended that bolts be used, rather than nails, when resistance to tension at joints is especially important. (18.) However, Zimmerman (35) found that railway spikes had practically the same resistance to withdrawal in creosoted wood as in untreated wood. Furthermore, it is open to question whether diagonal nailing is actually superior.

In ties and other timbers exposed to the weather, the type of preservative with which the wood is impregnated may have a distinct effect on the amount of splitting and checking that occurs in service (4). These *weathering effects,* which are common in zinc-chloride-treated ties, and especially pronounced in those used in semiarid regions, were found to be materially reduced in occurrence and severity in experimental ties treated with a mixture of zinc chloride and petroleum. It has also been observed that timbers impregnated with mixtures of creosote and coal tar or creosote and petroleum are less subject to splitting and checking than those treated with straight creosote. This apparent effectiveness of the tar and petroleum is presumably due to the water-shedding characteristics of these substances; by keeping the surfaces of the timber relatively oily, they tend to inhibit rapid moisture changes in the outer layers of the wood, thus reducing the alternate swelling and shrinking that result in checking and other evidences of weathering. As the result of this moisture-repelling property, the petroleum and coal tar may have some effect in increasing the mechanical life of ties and similarly exposed timbers.

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CHAPTER X

TREATING PLANTS AND EQUIPMENT

There is a tremendous diversity in the amount and cost of the equipment needed for the different methods of applying preservatives to wood. The simplest and least expensive apparatus is that required for brush treatments. At the other end of the scale are the very elaborate pressure plants, provided with several large treating cylinders, an assortment of woodworking machines, and modern labor-saving devices of all kinds and costing at least a million dollars. Between these two extremes, the plants and equipment represent all degrees of complexity and expense.

The kind and amount of equipment installed for any given process or type of treatment will naturally be influenced by local conditions and requirements, but should be based largely upon such factors as the volume and character of the timber to be treated and the degree of protection required for the wood. It is obviously uneconomical to build a large, expensive plant which will be operated far below its capacity, just as it is financially unsound to treat large quantities of timber by small-scale methods.

BRUSH AND SPRAY EQUIPMENT

If only a small amount of wood is to be brushed with creosote, a wad of rags or burlap on the end of a stick and a pail of cold preservative may be adequate for the purpose. But when such a treatment is to be applied on a scale that justifies the use of anything more than makeshift devices, attention may profitably be given to the type of brush to be employed and to methods of heating the oil. The size of the brush should be determined by the expanse of wood surface to be covered. The long-handled brushes commonly used for applying roofing pitch or cement are very serviceable for spreading preservative oils. The bristles should be wire bound or set in a material that is not affected by the preservative; rubber is not suitable, since it is attacked by creosote.

While creosote should be applied hot for best results, the inconvenience of heating the oil may not justify such preparation if only a small amount of wood is to be treated. The heating may be done in various ways. For small jobs, a plumber's blowtorch placed beneath a pail or other small container of oil will suffice; but for larger operations, a tar kettle set over an open fire or a blowtorch flame is more suitable. The heating should be carried on in a safe place, where no particular damage can be done by an accidental fire caused by overheating the oil. The fire hazard may be reduced by using steam coils or electric immersion heaters instead of open fires.

Portable paint sprayers or insecticide sprayers may be used instead of brushes, and are preferable for covering irregular surfaces or for coating the inside of bolt holes.* These devices should be so constructed that the handhold is at some distance from the nozzle, thus reducing the liability of the operators "burning" their skin through contact with the oil; the "pistol type" of sprayer is not suitable for applying creosote. The hose connections of the apparatus should be of oil-resistant composition.

STEEPING AND DIPPING APPARATUS

Tanks for steeping or soaking treatments should be sufficiently tight to avoid leakage, strong enough to support the weight of the timber and preservative, and constructed of materials that will not be seriously deteriorated by the preservative. Mercuric chloride or copper sulphate should not be used in iron or steel equipment, because of their corrosive action on such metals. Treatments with these preservative salts should be carried on in wood, concrete, or masonry tanks.

Some means must be provided to keep the wood from floating in the preservative during treatment. With small quantities of material this can be easily managed by pushing the wood to the bottom of the tank and weighting or bracing it down, but greater precautions are needed when larger volumes of wood are treated. Some plants are provided with a reserve preservative storage tank and pumping equipment, in which case it is possible to load the wood into the treating tank and brace it securely before the preservative is admitted. When this extra apparatus is available, the preservative may also be pumped out of the main tank upon the completion of the treatment, and the wood may be allowed to drip for a time before it is removed. The second tank may also be used as a mixing vat, for preparing extra quantities of preservative. If heavy timbers or large bundles of smaller pieces of wood are to be handled, some form of derrick or hoist may be used to advantage.

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* The pressure device illustrated in Fig. 61 is more effective for treating bolt holes than either a brush or a sprayer.

When wood is to be dipped in unheated preservative, the treatment may be carried out with much the same sort of equipment as is used for steeping. On the other hand, if the process involves the immersion of the wood in hot preservative, the apparatus required will be generally similar to that used for administering the hot bath in the hot-and-cold-bath treatment.

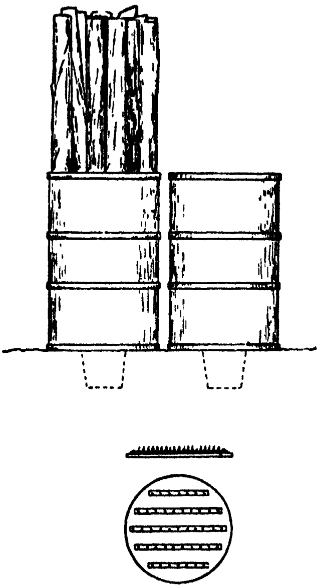


Fig. 74.—Fence-post creosoting tanks made from 110-gal. oil drums. Note method of constructing false bottom to prevent slipping and floating of posts. (*U.S. Forest Products Laboratory.*)

HOT-AND-COLD-BATH PLANTS

Hot-and-cold-bath plants differ from those designed for steeping wood in that they require some means of heating the preservative during treatment. The simplest equipment that will work effectively in butt-treating fence posts on a small scale consists of a single tank set over an open fire. The tank may be built especially for the purpose, or it may be made by cutting one head out of a 110-gal. oil drum (Fig. 74), the smallest size that will permit treating posts to the required height. The fireplace, over which the tank is placed, may simply be a hole dug in the ground, with a stovepipe at one end to furnish the necessary draft, or it may be a more elaborate firebox, made of brick and containing grate bars and draft doors. Open-fire heating must be rather carefully controlled, to keep the temperature of the creosote within the desired limits and to prevent the oil from boiling or splashing out of the tank and taking fire. Steam coils and electric immersion heaters are much safer and afford a better control of preservative temperatures, but it is seldom practicable to use such contrivances on small operations.

A very desirable improvement may be made in this simple type of post-treating tank by inserting a false bottom, set with screws having their points projecting upward. The posts catch on these points and are prevented from slipping around and floating in the preservative. The false bottom may be made from the head of an oil drum or any flat piece of metal, by riveting to it iron straps that have stout 1½-in. screws extending through them, as shown in Fig. 74. (4.)

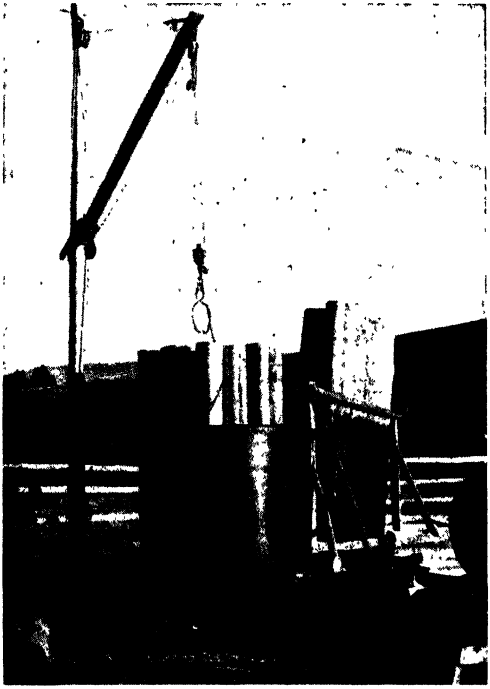


Fig. 75.—Single-tank plant for butt-treating posts, pole stubs, and small poles. Note hoist and drain rack. Tanks of this type have been successfully used for many years by the U. S. Forest Service. (*U. S. Forest Service.*)

Unless the posts to be treated are small and light in weight, it will probably be desirable to erect a platform on which the operator may stand. This should be built at the most convenient height for lifting the posts in and out of the tank. When heavy timbers are to be handled, a small derrick can be used to advantage. Single-tank plants (Figs. 75 and 76) are being used very successfully in the Rocky Mountain region by the U. S. Forest Service, for the butt-treatment of posts, pole stubs, and small poles.

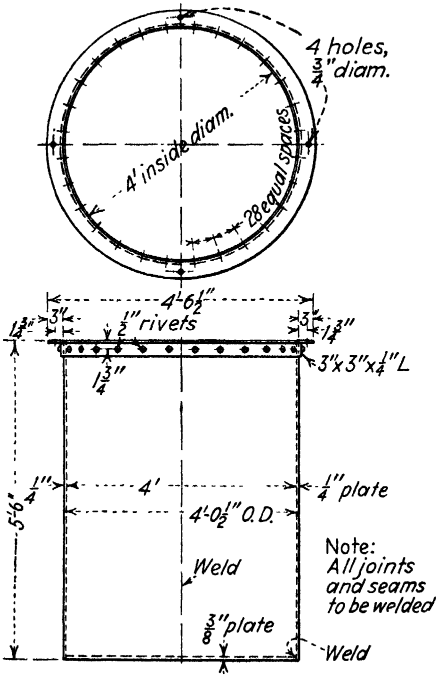


FIG. 76.—Working drawing of tank shown in Fig. 75. The tank is 4 ft. in diameter, 5½ ft. deep, made of ¼-in. tank steel with welded joints, weighs 600 lb., and is heated over an open fire. (*U. S. Forest Service.*)

A type of hot-and-cold-bath post-treating plant that is frequently described and illustrated consists of two wooden barrels, set several feet apart and connected by an iron pipe of large diameter. The oil is heated by building a fire beneath the pipe midway between the barrels. Such a plant cannot be recommended, however, for the barrels are usually not deep enough to permit treating the posts to the desired height, and, furthermore, it is practically impossible to keep them tight. The repeated heating of the creosote tends to dry out the wooden staves, causing them to shrink and open at the joints, thus leading to loss of oil and affording a distinct fire hazard.

In the operation of a single-tank post-treating plant, the treatment may be carried out by first heating the oil and wood and then drawing the fire and allowing them to cool. This method of administering the cold bath requires a long time, however, and a separate tank of unheated preservative is often provided to hasten the treatment. In this case, posts can be removed from the hot bath and placed immediately in the cooler creosote. This procedure has the disadvantage of requiring extra handling of the posts, however; and even when two tanks are available, they are often operated independently as separate units. When posts are to be given a full-length treatment of the regular hot-and-cold-bath type, the tanks must naturally be somewhat deeper or longer than the timbers. However, a simple dip treatment can be applied to the tops by merely reversing the posts after the butts have received the regular treatment.

When lumber is to be treated, a long narrow tank must be provided. A simple, small-capacity tank of this type (5) was made by cutting both heads from each of four 55-gal. oil drums and one head each from two others and then butt-welding the six drums end to end to form a long cylinder closed at both ends. This was then cut longitudinally into halves with a welding torch, forming two semicylindrical tanks. The tank for hot oil was supported between two 4-in. walls of concrete, and a firebox built beneath it. The other tank was set beside the first and used for the cold bath. A drain board was also provided, being so placed that when the treated lumber was lifted out of the cold bath and set on it, the dripping creosote drained back into the tank. A Z-shaped hook was used for handling the hot creosoted lumber. This was made from ½-in. round reinforcing iron, one end being fashioned to a dull chisel shape for inserting between the boards. A plant of this same type could be made from corrugated-iron culvert or any other available material of suitable size, shape, and character. When the preservative is heated by means of steam coils, the tank can be made of welded sheet iron set inside a wooden box or crate, as illustrated in Fig. 77. A thermometer should be used in all hot-and-cold-bath treatments, to permit proper control of preservative temperatures.

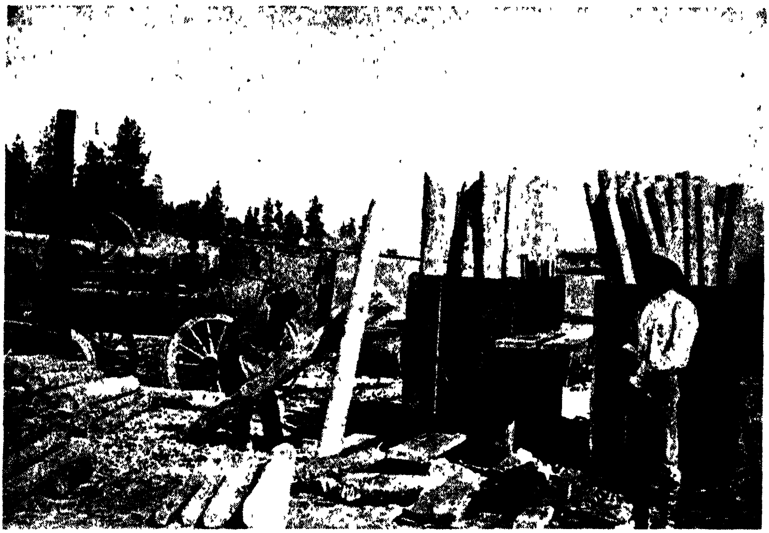


FIG. 77.—Two-tank post-treating plant formerly used by the U. S. Forest Service in California. The tanks were made of heavy galvanized sheet iron and supported in a wood frame. Steam was supplied by portable boiler. (*U. S. Forest Service.*)

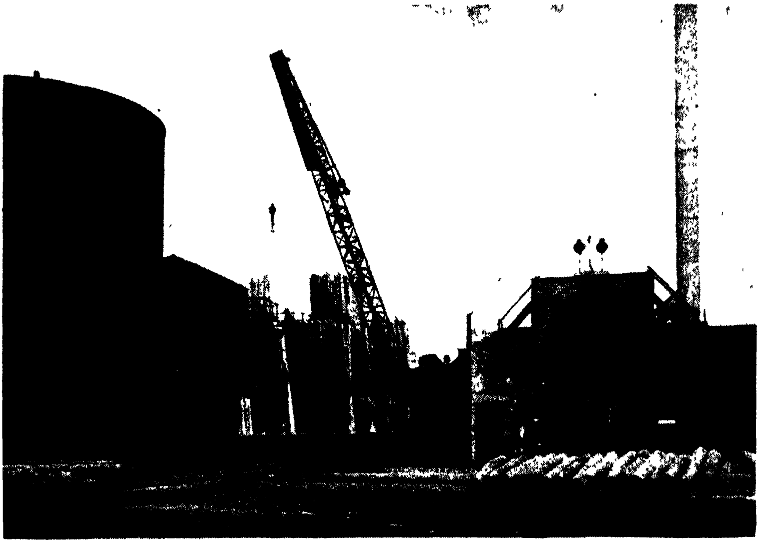


FIG. 78.—Butt-creosoting cedar poles at a commercial pole-treating plant. Note racks for supporting poles in tanks. (*Page and Hill Co.*)

Poles may be butt-treated in tanks similar to those used for posts; but larger and heavier equipment is required, and mechanical hoisting apparatus must be provided, because of the greater weight and size of the timbers. Commercial plants for butt-treating cedar poles are commonly equipped with two or more treating tanks, each provided on three sides with tall racks against which the poles are leaned (Fig. 78); one or more working and oil-storage tanks; a boiler plant for supplying the steam required to heat the preservative; pumps for moving the oil; indicating and recording thermometers, or combination temperature recording-controlling apparatus; a locomotive crane or other hoist; an incising machine; and equipment for gaining, roofing, and boring the poles. The bottoms or sides of the tanks are usually fitted with steam coils, which are covered with perforated iron plates or with gratings to protect the pipes from damage by the poles. An outside heat interchanger may be substituted for the steam coils, the oil being constantly circulated between this and the treating tank. In plants of this type, the usual practice is to pump out the oil at the end of the hot bath and then immediately refill the tank with unheated preservative. This avoids the cost and inconvenience of moving the heavy poles from one tank to another or the long period of time required when the preservative in the treating tank is allowed to cool to the desired cold-bath temperature. When this method of effecting the change in baths is used, however, separate storage tanks must be provided for the hot and cold oil.

PRESSURE PLANTS

The principal parts of a pressure-treating plant are the treating cylinder, with the pumps, tanks, thermometers, gauges, piping, valves, and other apparatus required to serve it; the boiler plant; the seasoning and storage yard, with its tracks and transportation facilities; and such supplementary equipment as hoists or other devices for handling the timber and machines for adzing, boring, framing, and incising the wood. The actual injection of the preservative is accomplished in the treating cylinder, which thus becomes the focus of the plant activities, although various other parts of the equipment may be equally necessary to the successful completion of the treating operation.

PLANT CAPACITY

A treating plant should have sufficient capacity to handle the amount of business that the company may reasonably expect to do, but excessive capacity is uneconomical and should be avoided. It is best to design the plant for present needs but at the same time to make adequate provision for conveniently enlarging the output, if increased business should later warrant such expansion. The size and number of the treating cylinders will naturally play an important part in determining the volume of timber that can be treated; but other factors, such as the species and form of wood to be impregnated, the method and degree of conditioning it for treatment, and the kind of preservative to be used may have an even more significant influence on the daily or annual production. Thus, a cylinder of moderate size may have a large annual capacity, if treatment is confined to such products as air-dry sap-pine poles, posts, or ties, which may be impregnated in 2 or 3 hr. On the other hand, if this same class of material is placed in the cylinder while still green and conditioned by steaming and vacuum, the treatment may require from 8 to 16 hr., and the annual production of plants that regularly follow such a practice is naturally only a fraction of what it would be if dry wood were treated. The most marked reduction in cylinder output is found in plants that treat green Douglas fir piles or heavy timbers, using the boiling-under-vacuum (Boulton) method of conditioning, and requiring from 24 to 60 hr. per charge. In such cases, several cylinders may be required to achieve the same production that is obtained with a single cylinder when shorter treating periods are used. It is evident, therefore, that the investment in treating equipment required for a given annual capacity is influenced to a marked degree by the character of the timber to be treated. The nature of the preservative may have a somewhat similar, although relatively minor, effect on plant capacity, since viscous preservatives, such as tar or petroleum solutions, may require a longer time for injection than those of low viscosity, such as straight creosote or water solutions.

TREATING CYLINDERS

The sizes of treating cylinders in use in the United States today vary over wide limits. Those employed for experimental purposes are quite small (Fig. 79), and some commercial cylinders as small as 5 ft. in diameter by 20 ft. or less in length have been installed at private plants for treating mine timbers and ties (Fig. 80). The largest cylinders thus far reported are 9½ ft. in diameter and 165 ft. long. One advantage of the large cylinders is that they can be equipped with tracks of standard gauge, thus providing greater flexibility in yard transportation, since both trams and standard railway cars can then be moved on the same rails. When plants are equipped with cylinders of medium or small diameter, it is necessary to have two types of track—narrow gauge for trams that must enter the cylinders and standard gauge for railway cars and locomotive cranes (Fig. 32). According to Shipley (6), the smallest cylinder in which it is advisable to install standard-gauge track is about 7½ ft. in diameter; 8 ft. is considered to be the most economical size when sufficient treating

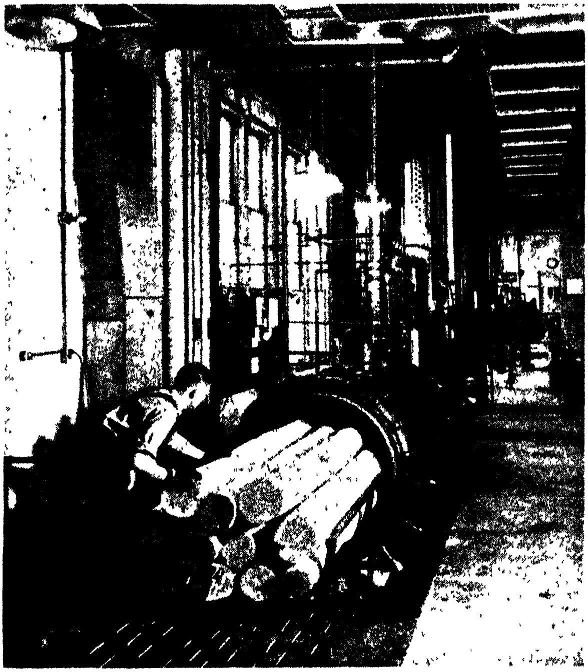


FIG. 79.—Experimental pressure-treating equipment at the U. S. Forest Products Laboratory. Size of cylinder in foreground is 3½ by 10½ ft. (*U. S. Forest Products Laboratory.*)

business is available to insure reasonably continuous operation. In 1923, only about 5 per cent of the treating cylinders in use had a diameter of 7½ ft. or more; of the new cylinders constructed since 1925, about half have been of these larger sizes, and approximately 40 per cent have been 8 ft. in diameter. Table XXII shows that a considerably smaller percentage of the cross-sectional area is occupied by the wood in cylinders 4 or 5 feet in diameter than in the larger sizes. The correlation between diameter and capacity for wood is further indicated by the length of cylinder required to hold a given amount of timber. For example, the cross-sectional area of a 9-ft. cylinder is about five times that of a 4-ft. cylinder, but the latter must be over eight times as long as the former if they are both to hold a thousand crossties. Figure 81 shows ideal loading diagrams for obtaining maximum capacity with timbers of different forms on standard-gauge tram cars.

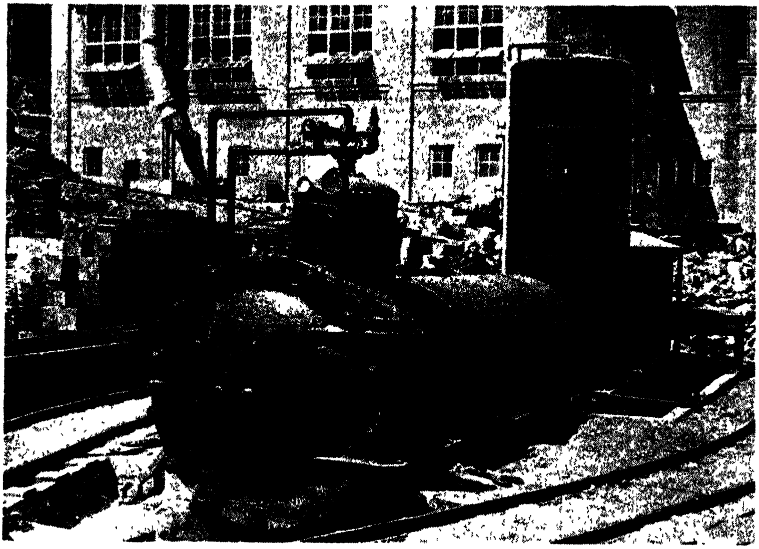
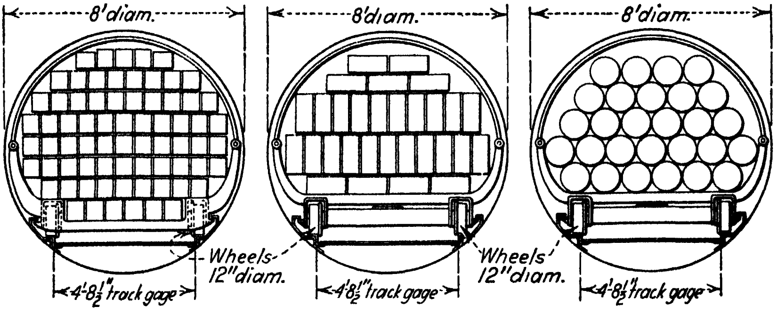


FIG. 80.—Small pressure plant for zinc chloride treatment of mine timbers at an Arizona copper mine. (*Miami Copper Co.*)

The capacity advantage of large cylinders over those of smaller diameter is significant only when there is a correspondingly greater volume of treating to be done. Some adjustment may be made in designing large cylinders for relatively low capacities by decreasing their length, but they should not be so short that they cannot hold the longest timbers that may need to be treated. Large cylinders are definitely uneconomical for the treatment of miscellaneous small lots of different kinds of timber.

The cylinder shell and supplementary equipment should be designed to withstand any working pressures that it may be necessary to apply. While the pressures generally used are within the range of from 100 to 185 lb. per square inch, the operator should be able to run them up to 200 or even 250 lb. with perfect safety, if such maximums are required to accomplish the desired results.



Loading of 7"x 8" cross ties

Loading of 7"x 16" timbers on bolster trucks

Loading of piles on bolster trucks

FIG. 81.—Typical loading diagrams for an 8-ft. treating cylinder. (*Courtesy Railway Age and Grant B. Shipley.*)

Because of the wide variations in temperature to which a treating cylinder is subjected, it must be so mounted that it is free to expand and contract. This is done by placing the cylinder on saddles resting on the foundation piers. It may be anchored to one of the saddles, in which case it is free to move over the others at will.

Cylinder Doors.—Cylinders may be built with doors at one or both ends (9). A double-end cylinder requires a larger door crew or longer time to open and close the doors than a single-end one and in that respect is more expensive to operate. On the other hand, it permits continuous movement of wood from the seasoning or storage yard, through the cylinder, and to the loading dock, with a minimum of tracks, switches, and crossovers; the incoming charge is used to push the treated charge out of the cylinder. With a single-door cylinder, the treated charge must be pulled out and placed on a passing track (Fig. 2) before the

TABLE XXII.—COMPARATIVE CAPACITIES AND OTHER DATA ON TREATING CYLINDERS OF DIFFERENT SIZE (6)

Diameter of treating cylinder, inches	108	96	90	84	74	60	48
Gauge of track in cylinder, inches	56½	56½	56½	30 or 36	24	24	18
Number of 7- by 8-in. sawed ties loaded on each tram	94	71	60	53	38	21	11
Cylinder area, square feet	63.62	50.26	44 18	38 48	29 17	19.60	12.56
Area taken up by crossties, square feet	36.55	27 60	23 33	20.61	14 77	8.16	4.28
Cylinder area taken up by crossties, per cent	57 45	54.92	52.80	53.55	50 65	41.66	34.05
Area taken up by lumber, square feet	32 66	23.33	20 22	18 66	13 22	7.78	3 89
Cylinder area taken up by lumber, per cent	51 34	46.42	45.77	48.50	45 32	39.67	30.95
Area taken up by piling, square feet	29.85	22.77	18 85	17.28	13 35	7 07	3.92
Cylinder area taken up by piling, per cent	46.91	45.31	42.67	44.90	45 77	36 06	31.26
Weight of cylinder shell per lineal foot for 200 lb. working pressure, pounds	1200	940	810	700	560	380	280
Weight of cylinder shell per lineal foot per crosstie, pounds	12 76	13.15	13.47	13 07	14.74	17.9	24 64
Length of cylinder for each 1000 crossties 8 ft. long, feet	88	112	136	152	208	384	728
Length of cylinder for each 1000 crossties 8 ft. 6 in. long, feet	93.5	119	144.5	161.5	221	408	773.5
Number of tram cars required for each 1000 crossties	11	14	17	19	26	48	91

next charge can be pushed in. No general rule can be given for deciding between the two types, although the single-door cylinders are generally preferred, being definitely in the majority today. Each installation is a separate problem, requiring expert study of all of the local factors involved, of which the area and shape of the available yard space are particularly important.

The doors in modern plants are generally hinged to one side of the cylinders (Fig. 82), although in some installations they are hung on cranes set beside the cylinders or on traveling hoists which move back and forth in front of them. When closed, the doors are tightened by means of heavy bolts which rest in slots in the rim of the door and the end of the cylinder. The bolts are generally tightened and loosened by means of hand wrenches, but power wrenches are now being used in some cases. In some of the older plants, the doors were fastened in place by a many-fingered "spider" arrangement, operated by a single handwheel and screw at the center, but levers of this type were found to be less effective than bolts. Special gaskets are provided for the bearing face of all doors, to afford the necessary tightness when high pressures are applied within the cylinder.

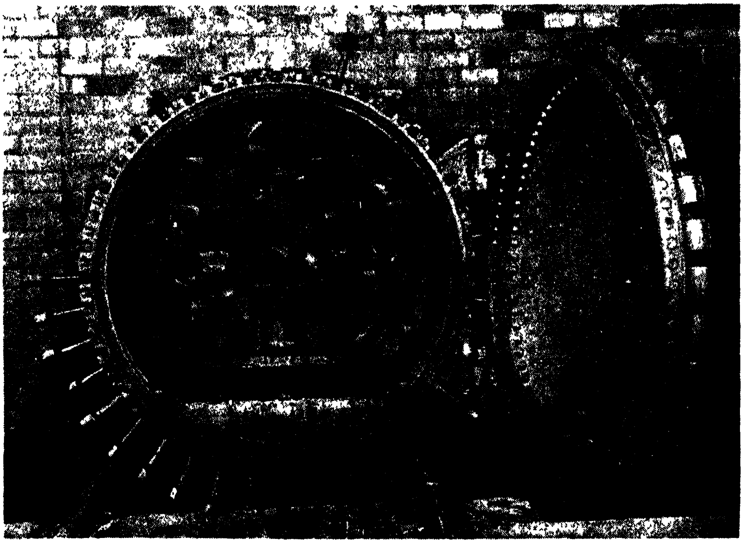


FIG. 82.—End view of a large treating cylinder. Note hinges, slotted door, and bolts. (*The Wood Preserving Corp.*)

Guard Rails.—In addition to the tracks on which the trams are run, some arrangement has to be made to prevent the loaded cars from floating when the cylinder is filled with preservative. This is accomplished by means of guard rails, which are fastened to the side of the cylinder near the track rails. The trams are provided with lugs, so placed that they pass beneath the flanges of the guard rails when the cars are moved into the cylinder and thus keep the trams from leaving the tracks (Figs. 81 and 82).

Heating Units.—The cylinder must be provided with some means of heating the preservative, in order to maintain the proper temperature during the treating process. The common practice is to install steam coils in the bottom of the cylinder, below and between the tram tracks, the size and length of pipe being determined by the amount of heating surface desired. The ordinary type of steam coil, made with elbows or return bends, is not very satisfactory for this work, as it is inclined to develop troublesome leaks and is not easy to maintain in good order unless all of the joints are welded. A more satisfactory type consists of a series of double steam pipes, one within the other; the steam enters at the center of the cylinder, flows to both ends of a coil through the inner pipe, and returns to the center through the outer pipe. Each pipe is free to move independently of the other (except at the center of the cylinder), thus reducing shrinkage and expansion stresses and decreasing maintenance costs. The amount of heating surface is regulated by the number of coils used. It is considered good practice to place perforated cover plates over the coils between the rails, thus reducing the tendency of chips and other debris to collect around the pipes and decrease their effectiveness.

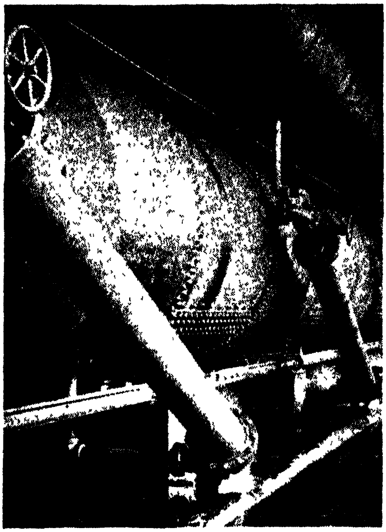


FIG. 83.—Outside heating units on a creosoting cylinder. A Rueping cylinder may also be seen mounted above. (*U.S. Forest Products Laboratory.*)

Treating plants are sometimes equipped with outside heating units (Fig. 83), instead of cylinder coils. These units consist of a multiplicity of steam pipes, placed in a section of large pipe or similar container. The preservative is continually circulated during treatment, being taken from the bottom of the cylinder by convection or by a pump, passed through the heater, and made to flow back into the top or side of the cylinder. The rapidity with which the preservative is heated is determined by the steam pressure and amount of heating surface in the unit, and by the rate at which the preservative flows through it. Several heaters may be required to serve a single treating cylinder. Strainers can be installed in the circulating lines to collect coarse particles of dirt, bark, and wood chips, and the heaters are so constructed that they can be disconnected and cleaned while the cylinder is in operation.

It is usually considered desirable to cover the treating cylinders with suitable insulation (*lagging*) in order to conserve heat and avoid unnecessary waste of fuel. The insulation also keeps the temperature of the retort house at a reasonable point and provides more comfortable working conditions for the operators.

TANKS

Operating Tanks.—The efficient operation of a treating plant requires a variety of auxiliary tanks, of which a *working tank* is probably the most important. In most plants, this is the tank from which the preservative is drawn by hydraulic pumps to fill the treating cylinder and to impregnate the wood and to which the preservative is returned after the treatment is completed. The working tank is calibrated, so that the amount of preservative that it contains can be determined at any time; if there is no waste or other loss of liquid, the difference in volume or weight of preservative before and after treatment represents the amount absorbed by the charge of wood. The amount of preservative in the tank may be indicated by a float, which activates a pointer on a scale; by a mercury column whose height is determined by the weight (depth) of preservative; by scales which weigh the tank and its contents; or by any other device that gives sufficiently accurate readings. A float or depth gauge is especially suited for use in a vertical, cylindrical tank, in which the amount of preservative per unit of height is the same throughout the entire depth of the container. In one type of float-gauge indicating device the float merely pulls a pointer up and down a scale board, while in another type it actuates one or two pointers on a dial (Fig. 84); the scale board or dial may be calibrated to read either in tank feet and fractions or directly in gallons. Float gauges usually do not indicate with a high degree of accuracy, and, furthermore, their efficiency is inversely proportional to the square of the diameter of the tanks with which they are used. For example, such a gauge will give much more accurate readings with a vertical cylindrical tank, 5 ft. in diameter, in which an inch in depth is equivalent to only about 12.3 gal., than in a similar tank 25 ft. in diameter, in which the same depth is equivalent to 306 gal., or twenty-five times as much. When float gauges are used, it is an obvious advantage to have the volume per tank foot as low as practicable. However, the tank must contain enough preservative to fill the voids around a charge of wood in the treating cylinder and also supply the required absorption. Working tanks should be equipped with steam coils or other devices for keeping the preservative hot, and it is also desirable to provide perforated air pipes or other contrivances which may be used to agitate the preservative and keep it uniformly mixed.

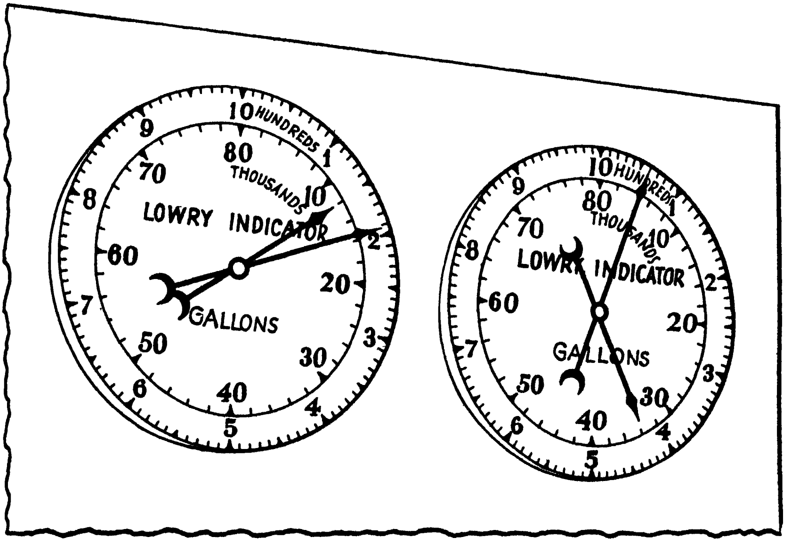


FIG. 84.—Tank gauges of dial-reading type. (*American Creosoting Co.*)

In plants operating with the Rueping process, the cylinder may be filled, after the air pressure has been applied to the wood, by pumping the preservative from the working tank and at the same time allowing the air to escape at a rate that keeps the pressure constant. Often, however, a special pressure cylinder, or *Rueping tank*, is mounted in a horizontal position directly above the treating cylinder (Fig. 83) and used for the filling operation. An amount of preservative sufficient to fill the voids in the loaded cylinder is placed in this tank and maintained under the same pressure as the preliminary air to which the wood is subjected. The treating cylinder is filled by allowing the preservative to flow in by gravity, while the displaced air moves up into the Rueping tank. The additional preservative required for treatment is then drawn either from a working tank or from a separate pressure tank.

A special *pressure tank* is used when the preservative pressure is applied by means of compressed air instead of by a hydraulic pump. This tank is designed for high working pressures and is usually required to be only large enough to contain the amount of preservative that will be absorbed by the charge of wood. After the treating cylinder has been filled from a working or Rueping tank, the line to the pressure tank is opened, and the desired pressure applied by admitting compressed air into the top of the pressure tank. Such tanks are frequently mounted on scales, so that the weight of the preservative forced into the treating cylinder can be read at any time during the impregnation period. When not placed on scales, the tanks are fitted with drain cocks or gauge glasses, so that the height of the liquid can be checked as the treatment progresses.

At the conclusion of the pressure period, the preservative is either allowed to run by gravity into a *drain tank*, from which it is returned to the working or Rueping tank, or pumped or blown directly from the cylinder to the operating tank.

Storage Tanks.—Large storage tanks are standard equipment at plants treating with preservative oils (Fig. 85). Such containers make it possible to effect definite savings through large quantity purchases of oil, and also provide an adequate reserve supply in the event of shipping delays which might otherwise cause a plant to shut down. Plants located along the seaboard usually have a storage tank into which creosote can be pumped directly from ships; the Atchison, Topeka, and Santa Fe Railway Company maintains a 4-mile pipe line from shipboard to four storage tanks, located at its National City (Calif.) treating plant and having a combined capacity of about 1,320,000 gal. of creosote (1).

Creosote storage tanks usually have closed tops, which serve to keep out dirt and water and also prevent loss of oil by evaporation. When open-top tanks are used for the storage of coal-tar creosote, evaporation can be prevented by maintaining a layer of water on top of the preservative, but this method naturally cannot be used for oils lighter than water. Water-borne preservatives do not require so much tank storage space as oils, for they are shipped and stored either in solid form or in concentrated solution and mixed with water as needed.

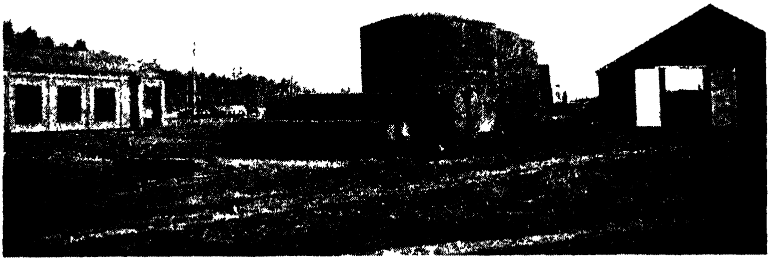


FIG. 85.—Air-storage (smallest pair), vacuum-storage (medium-sized pair), and oil-storage (largest three) tanks, at a Rueping-process plant.

Receiving Tanks.—Receiving or unloading tanks are usually provided in plants that receive railway shipments of preservative oils. They are located underground, beneath a railroad siding, and the preservative is dumped directly into them from the tank cars. Steam connections are required, so that steam can be circulated through the coils in the tank car to warm the preservative thoroughly and make it completely liquid before it is dropped. In the cold parts of the country, fuel can be saved by building a housing over the receiving tanks, so that the tank cars can be brought under cover while their contents are being heated preparatory to draining. Large plants should be so equipped that several cars can be dumped at once. The preservative is pumped from the receiving tanks to the storage, working, or mixing tanks, as desired.

Mixing Tanks.—Tanks for mixing preservatives are required at plants using salt solutions or mixtures of creosote with petroleum or tar (unless the oils are purchased already mixed). The distinctive feature of these containers is the provision for agitating the preservative. This is commonly done by blowing air through perforated pipes located in the bottom of the tank. Perforated steam coils are sometimes used with water-borne preservatives, when both heating and stirring are desired; the steam condenses and adds some water to the preservative, but the operator can compensate for such dilution by starting with a stronger solution. Mechanical stirrers of the propeller type may also be used, being especially suited for tanks of small to moderate size. Mixing tanks should be provided with adequate heating units, since it is often desirable to heat the preservative, especially if it is to be pumped directly to a working tank.

Oil-recovery Tanks.—At plants using preservative oils, it is very important to have a *sump*, or settling tank, into which all waste water and oil drippings from the various plant operations will flow. The water condensed during the steaming or vacuum stages of treatment often carries appreciable quantities of oil, which should be removed as completely as possible before the water leaves the plant. Some oil may also escape directly from the cylinder, particularly when the door is opened after treatment. The use of recovery tanks not only effects a saving in preservative but also reduces the contamination of streams by oil-laden water.

The sump should be of such size that the water will flow through it very slowly, giving the oil plenty of time to settle out. The outlet should be near the top of the tank, so that the oils heavier than water will be trapped in the bottom; the oils lighter than water can be trapped by a series of baffles, each extending from above the surface of the liquid to several feet below it. Filter boxes or screens filled with excelsior are commonly used in sump tanks, to aid in separating the oil from the waste water.

Tank Material.—The tanks used for commercial wood preservation are almost all made of steel, for this is usually the cheapest material of suitable properties. Wood tanks may be used for water solutions, but they have no particular advantage unless the preservatives contain chemicals corrosive to steel. Either wood or copper containers are suitable for the copper solutions used in the preliminary steps of preparing certain proprietary preservatives, but copper tanks and copper or brass fittings should not be used for ammoniacal solutions. Wood tanks are not suited for holding hot creosote, since the oil causes the wood to shrink and thus leads to heavy leakage of preservative.

High-pressure Air Receivers.—Tanks for storing air under high pressure (Fig. 85) are installed at plants using the Rueping process or the compressed-air method of applying preservative pressure. They facilitate the operation of such plants, since they provide either a quick or gradual application of air pressure, as needed. Such tanks should be built with a high factor of safety and provided with adequate safety valves. They should also be equipped with effective drain valves, to minimize the danger of explosion due to accumulation of oil and water in the tanks.

Vacuum-storage Tanks.—Storage tanks are also used occasionally to aid in the quick application of vacuum (Fig. 85). When a tank in which a high vacuum has been created is opened into the treating cylinder, the equalization of pressure creates a partial vacuum in the cylinder. This procedure makes it possible either to reduce the time required for a pump to produce the desired vacuum in the treating cylinder or to use a smaller pump than would otherwise be needed to create the vacuum in a specified time. According to Shipley (7), several plants using the vacuum-storage system and a small vacuum pump are able to get 15 in. of vacuum in the cylinder in 1 min., 18 in. in 3 min., and 22 in. in 9 min. The ratio of the volume of the vacuum tank to the amount of cylinder space to be evacuated has a direct bearing on the amount of vacuum that can be produced by "cutting in" the storage tank.

PUMPS

A very small plant may be able to operate reasonably well with only a vacuum pump and a hydraulic pressure pump, for, with suitable pipe connections, the pressure pump can be made to move the preservative in and out of any tank or treating cylinder as well as to apply the treating pressure. Larger plants require several pressure pumps, so that a number of operations can be carried on at once, and also so that the piping system need not be unduly complicated. High-speed centrifugal pumps are often used for rapidly filling or emptying the treating cylinder and sometimes for applying the preservative pressure. When hydraulic-pressure pumps are used in plants having more than one treating cylinder, a separate pump should be provided for each cylinder so that it can be operated independently of the others. It is desirable to have additional pumps for general service and for moving the preservatives from one tank to another, especially if the tanks cannot be drained by gravity and are not built to withstand air pressure.

When the compressed-air system is used and sufficient air-storage capacity is provided, only an air compressor and a vacuum pump are required (7). The piping system is also greatly simplified under such circumstances.

A single vacuum pump of sufficient capacity can be made to serve several treating cylinders, although some delay may result when two or more cylinders need to be evacuated at the same time. A vacuum-storage tank increases the practicability of operating with but one pump. For the quick evacuation of a treating cylinder after a charge has been steamed, a pump of the steam-ejector type is often preferred.* However, this kind of pump is not considered so suitable as the reciprocating type for pulling a preliminary vacuum or for creating a vacuum during the Boulton conditioning treatment (7).

Every plant should be equipped with a fire pump or some other effective means of getting water to a fire quickly. Special foam-producing apparatus is desirable for combating oil fires.

CONDENSERS

A surface condenser must be inserted in the vacuum line, in order to cool the vapors and condense out the oil and water before they reach the vacuum pump. The condenser should be so constructed, or so connected in the line, that the condensed liquids can be collected and conveniently measured and also that the oil can be separated from the water and saved. The collection, measurement, and separation of the condensate are especially important when wood is being conditioned by the boiling-under-vacuum (Boulton) method; one objection to the use of the steam-ejector type of vacuum pump for the Boulton treatment is that it does not conveniently permit the collection and measurement of the liquid.

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* It is interesting to note that this method of creating a vacuum in a treating cylinder was mentioned in a French patent (No. 11,195) issued to Jean Robert Bréant on Apr. 14, 1838.

Piping and Valves

The efficient operation of treating cylinders, pumps, and tanks requires a suitable system of pipes and valves connecting the various pieces of equipment. The piping system is likely to be involved at best, and great skill is required to avoid unnecessary expense and complications in its installation. The control valves for the piping system and the operating switches or throttles for the various pumps should be concentrated as far as practicable at one place (Fig. 86); in large plants, it is customary to have a system of header pipes and valves near the gauge board, a point from which the operator can control the temperature, pressure, and vacuum in any treating cylinder and move preservative into or out of any cylinder or operating tank, as desired. The first cost of such an installation may be high, but the saving

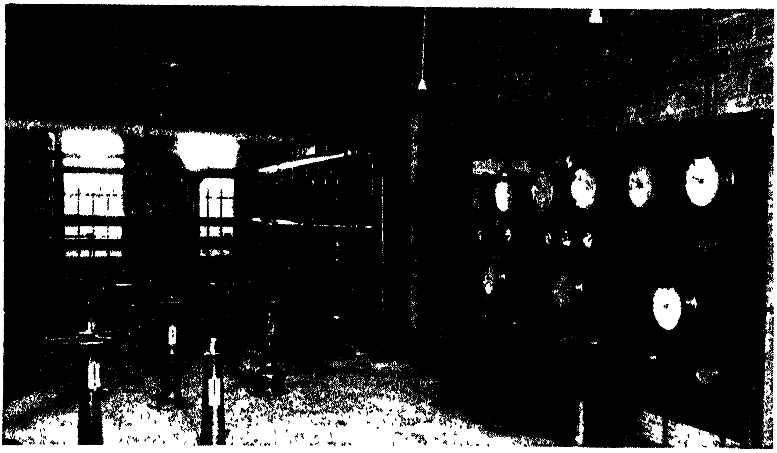

Fig. 86.—Main operating valves and gauge board at a commercial treating plant. (*Foxboro Co.*)

in operating time and the convenience to the operator will more than justify the expense.

THERMOMETERS AND GAUGES

Thermometers and gauges for indicating pressure and vacuum are necessary in the operation of a treating plant, for without them the treating conditions cannot be controlled within the desired limits. Such instruments must be kept in adjustment at all times and be calibrated at frequent intervals to insure their correctness.

Thermometers should be placed in all tanks and cylinders in which heated preservatives are kept. It is customary to screw a special fitting, or *thermometer well*, into the shell of the tank or cylinder and to fit the bulb of the thermometer into it. This well not only protects the bulb from damage, but it also permits the removal or insertion of the thermometer at will, regardless of the conditions within the tank or cylinder. The location of a thermometer is highly important, for the temperature of a preservative may vary widely in different parts of a tank. If inserted near a steam coil, the instrument will read too high; if placed where the preservative does not circulate freely, it may read too low. Long-stemmed thermometers, which reach deeply into the preservative, give more nearly correct readings than short-stemmed instruments which have their bulbs close to the shell of the tank, but the former type cannot be used to advantage in the treating cylinder, because of the danger of breakage.

Recording Thermometers.—In addition to the above-mentioned indicating thermometers, it is desirable to attach recording instruments to the treating cylinder and thus obtain a complete record of the temperatures throughout each treatment. This temperature record is usually filed with the other data for each charge or is given to the purchaser for whom the timber was treated.

A very useful type of instrument is the combined temperature recorder and controller, which not only makes a time record of the temperature but also controls it within specified limits. The controller device may be set at any temperature above atmospheric, which will then be maintained within two or three degrees by the automatic operation of the heating units. When the temperature drops below the set point, the steam is turned on;

and when it goes above that point, the steam is turned off. Such automatic devices can often be used to great advantage, in place of manual control.

Pressure Gauges.—Gauges are required on all tanks and cylinders in which pressure is applied. These may be of the indicating, recording, or controlling type. The location of these instruments does not usually affect the readings to the extent that it does with thermometers. It is important, however, to have the pressure gauges connected by pipes that are tight and of adequate size, as well as to provide devices that will prevent dirt from accumulating and filling up the connecting pipes. When the gauges are to be used where vacuum is also applied, they should preferably be of such a type that they will not be injured when the cylinder is evacuated.

Vacuum Gauges.—These gauges must be installed on all treating cylinders and also on vacuum-storage tanks. Each plant should also have a mercury vacuum gauge, to serve as a standard for checking the other kinds. It is desirable to use gauges of a type that can safely withstand pressure, so as to avoid damage in case pressure is accidentally applied.

Combination Gauges.—Gauges can be obtained that will record temperature, pressure, vacuum, and time simultaneously and give the complete history of a treatment on a single chart. This is a distinct advantage to any one making a subsequent study of the treatment.

Whenever recording, controlling, or combination types of gauges and thermometers are used, instruments of the indicating type should also be installed. The latter are so much simpler in construction and operation that they are less likely to get out of order and can be used to check the accuracy of the automatic devices.

Gauge Boards.—It is customary to mount as many gauges and thermometers as practicable on a gauge board at a central location (Fig. 86), so that they can be constantly under the observation of the plant engineer. In this way, the operator can keep a check on the conditions in each treating cylinder without constantly running around to take readings.

YARD EQUIPMENT

One of the most important factors in the economical operation of a pressure plant is the arrangement of the seasoning and storage yard and its transportation system. As previously mentioned (page 140), the yard should be located on high ground, supplied with adequate drainage facilities, conveniently arranged in streets and alleys, and provided with adequate trackage.

Yard Tracks.—It is usually necessary to have standard gauge track throughout the yard, to permit the effective operation of locomotive cranes and the movement of the regular railroad cars which are used to bring loads of timber, preservatives, and fuel to the proper locations at the plant and also to pick up the outgoing shipments of treated material. In plants that carry small stocks of timber in seasoning or storage piles and treat most of the material as it is received, the tram-track system leading into the treating cylinder may be very short, extending only far enough for the trams to receive the incoming timber from railroad cars, barges, docks, or framing machines and to take the treated material to the loading areas for shipment. In most plants, however, the tracks are continued throughout the yard, so that the trams may be loaded directly from seasoning piles at any point, with a minimum of handling. When the plant is equipped with treating cylinders of large diameter, the tram tracks may be of standard gauge (Fig. 2), but with smaller cylinders it is necessary to provide a narrow-gauge system. In the latter case, standard- and narrow-gauge tracks may alternate throughout the yard, or a three-rail system may be used, with the narrow- and standard-gauge tracks placed on the same ties (Fig. 32). Any yard layout that includes both standard- and narrow-gauge tracks necessarily requires complicated switches and crossovers and is considerably more expensive to build and maintain than a single-gauge system. The cost of transporting timber around the yard and through the woodworking machines to the treating cylinder and the shipping platform is increased very decidedly by unnecessary switching, back hauls, delays, and congestion of tram cars. To obtain maximum economy in operation, the plant transportation system requires very careful planning. Dead-end tracks are strongly condemned as uneconomical (9).

Motive Power.—This is another important factor in the economical movement of timber through the plant. A variety of types of motive power are employed (8), including horses, tractors, cables operated by winches, ordinary coal- or oil-fired steam locomotives, and electric, gasoline, Diesel, or fireless-steam locomotives (Figs. 87 and 88). One horse or a team can sometimes be used for hauling several empty trams or a single loaded tram, but draft animals cannot be employed for moving charges in and out of the treating cylinder and seldom afford economical transportation. Winches and cables have been used extensively in the past, particularly for moving untreated charges into the cylinders and treated charges out to the loading platforms. A cable cannot advantageously be extended very far from a winch, however, so that only a very limited territory can be covered from a given setup. It is generally most economical to use some type of locomotive, the size of which should be determined by the amount of power required to move a charge into or out of the cylinder, since that is the heaviest job it will usually be called upon to perform.

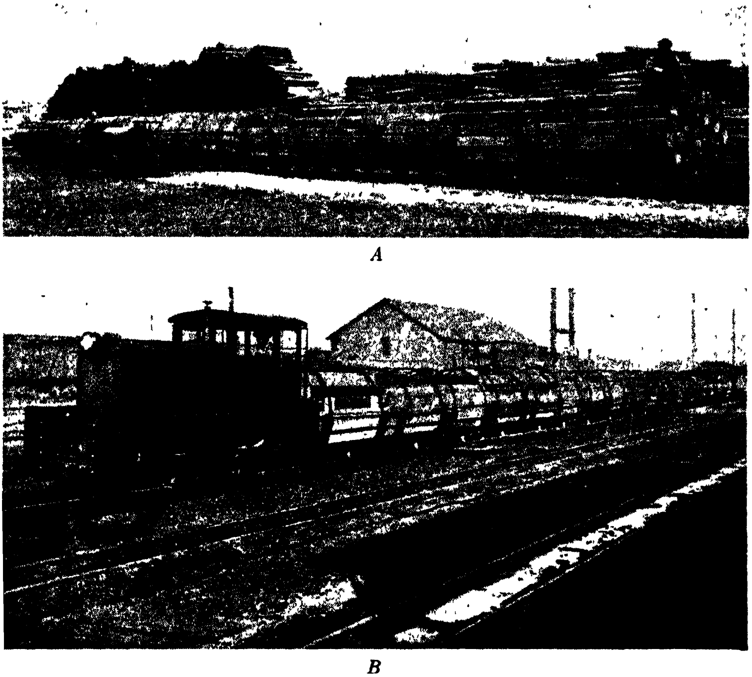

Fig. 87.—Tractor (*A*) and gasoline-powered locomotive (*B*), for moving timber charges and trams. (*C. B. and Q.R.R.*)

Railroad switch engines are very generally used at railroad treating plants, while smaller locomotives are more common at

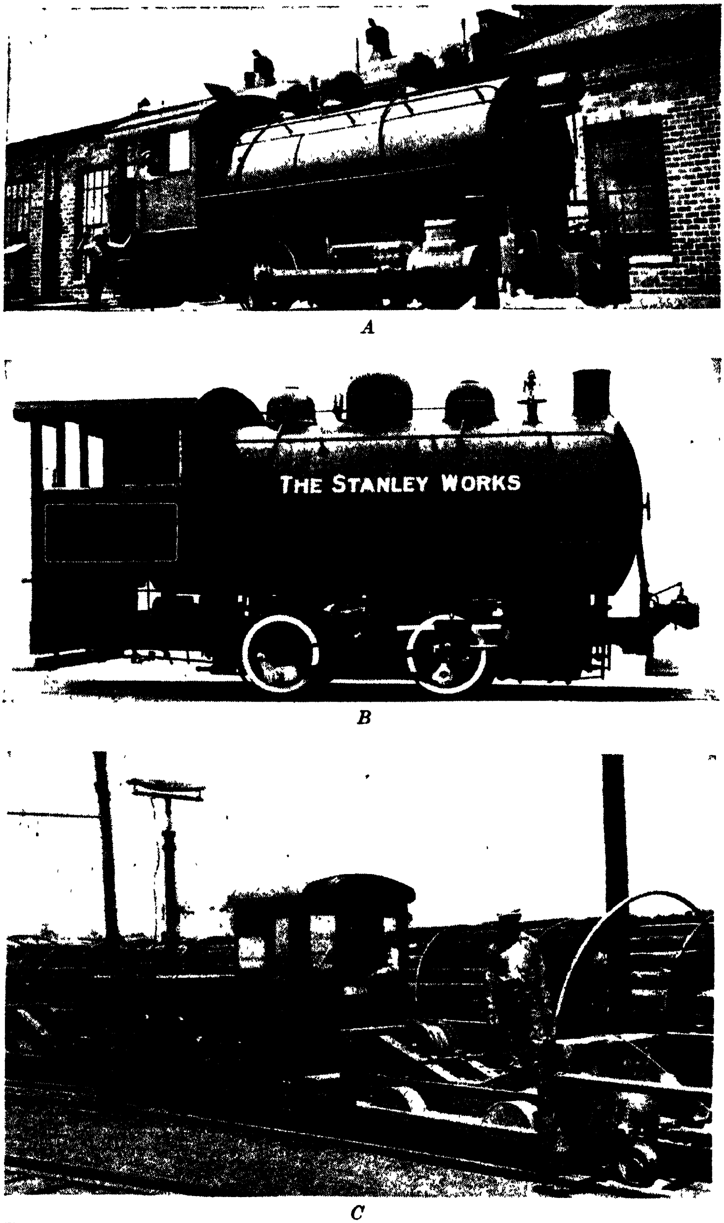

FIG. 88.—Forms of motive power used at wood-preserving plants. *A*, fired-steam locomotive; *B*, fireless-steam locomotive (*H. K. Porter Co.*); *C*, electric locomotive (*American Creosoting Co.*).

commercial plants. The disadvantages of an ordinary steam locomotive are that, when steam is up, it is almost as expensive when idle as when working, that it is somewhat of a fire hazard, and that some labor union rules require two men for its operation. Small fireless-steam locomotives, designed to operate at low pressure, are used at some plants, thus eliminating the fire hazard. These engines contain insulated, high-pressure-steam storage tanks, which are charged from the plant boilers, as required. However, such locomotives must always be within reach of their steam supply and are not suitable for making long runs. On the other hand, they do not require a fireman, which is a distinct advantage in operating cost.

Electric locomotives have been used successfully at some plants. They can be operated by one man and do not constitute a fire hazard. However, they require the installation of a trolley-wire system throughout the yard, with the attendant danger to workmen and interference with the freedom of crane operation. A more recent type of locomotive, which is free from fire hazard, requires only one operator, and burns fuel only when working, is the gasoline, or Diesel-engine, locomotive, which is available in various forms and sizes. The smaller sizes can be powered by standard automobile engines, which makes for convenience in obtaining replacement parts. For locomotives weighing more than 25 or 30 tons, the gasoline-electric or Diesel-electric drive is recommended; it is claimed that the maintenance on such equipment is lowered sufficiently to offset the high first cost (8).

Cranes and Hoists.—Some kind of crane or hoist is a practical necessity in any plant at which poles, piles, bridge timbers, or other heavy materials are handled. Steam- or gasoline-locomotive cranes, operating on yard tracks, are most commonly used (Figs. 78 and 89), and these can also be employed to move cars about the yard. The sizes and types of the available cranes vary greatly, and the plant operator has a wide choice. Most plants are equipped with several cranes, so that light handling can be done by lightweight, speedy, inexpensive machines and the heavier work by heavier, slower, and more costly equipment. At some plants, particularly those engaged in butt-treating poles, crawler-type cranes (Fig. 90) may be used. They require no track and can be used anywhere in the yard. Gasoline-powered

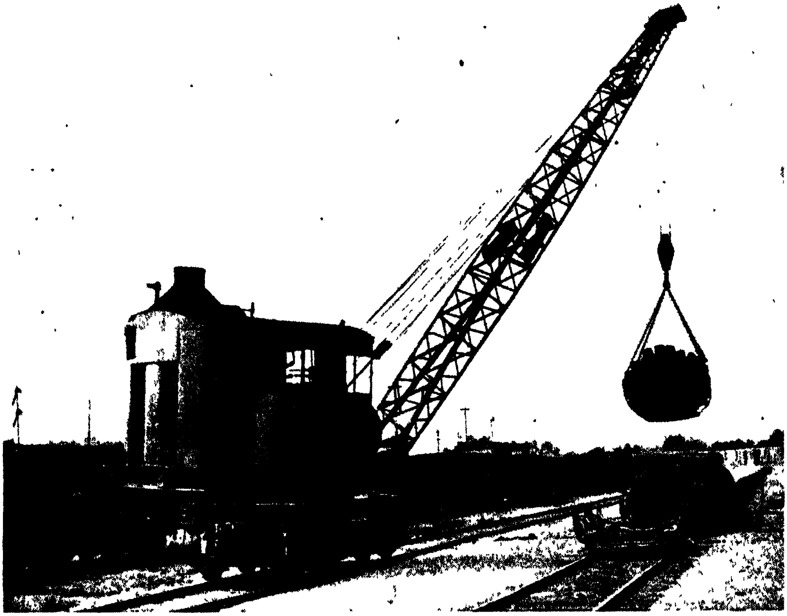

FIG. 89.—Locomotive crane loading treated ties into cars for shipment. (*The Wood Preserving Corp.*)

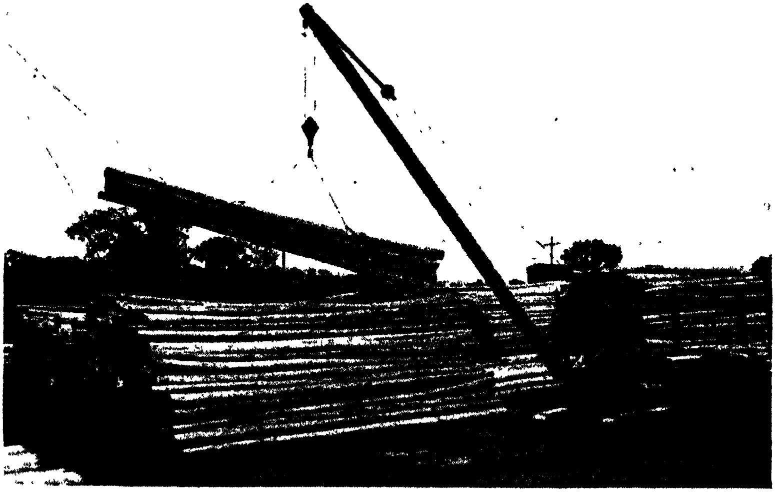

FIG. 90.—Caterpillar-tractor crane handling poles in a cedar pole yard. (*Valentine Clark Co.*)

cranes are increasing in popularity, because they require no fireman, present practically no fire hazard, and are said (8) to effect a considerable saving in fuel and maintenance.

In addition to locomotive cranes, various types of stationary derricks and overhead traveling hoists (Fig. 91) are used where

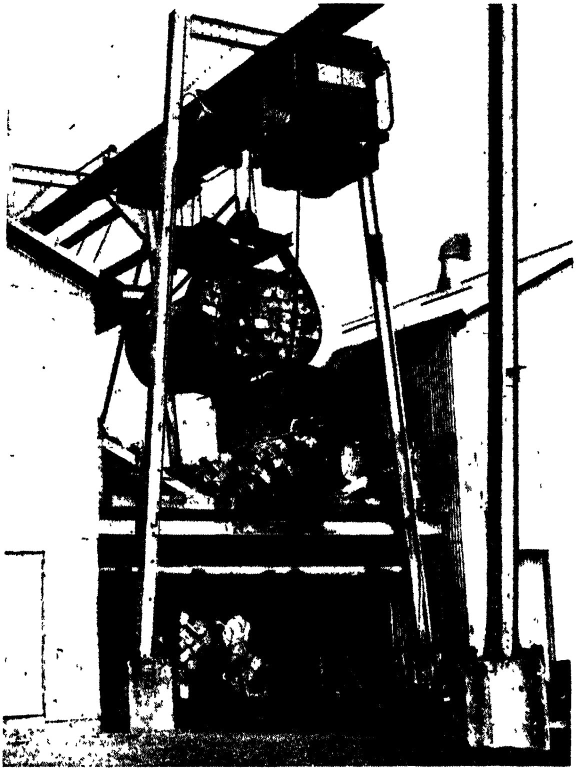

FIG. 91.—Monorail crane for handling ties at adzing and boring mill. (*The Wood Preserving Corp.*)

there is a large amount of lifting to do in a limited area. These machines are especially well adapted for such work as loading treated ties or timbers from trams to railway cars; moving ties from trams to adzing and boring machines; hoisting poles into butt-treating tanks; lifting poles and piles out of the water, as is done at Pacific Coast plants located on deep water; and other similar jobs.

The efficiency of a crane or hoist depends in part upon the hooking devices used for picking up the load. These may vary according to the character of the loads to be handled and the ideas of the individual plant operators, and include large grappling hooks for picking up entire tram loads of ties; single "ice-tong" hooks for lifting single poles, piles, or other large timbers; single slings; double slings or hooks with spreaders, for handling lumber; and a great many other kinds (8). When hooks are used, they must be of a type that will not dig through the impregnated shell in treated timbers, tear out splinters, or otherwise seriously damage the wood.

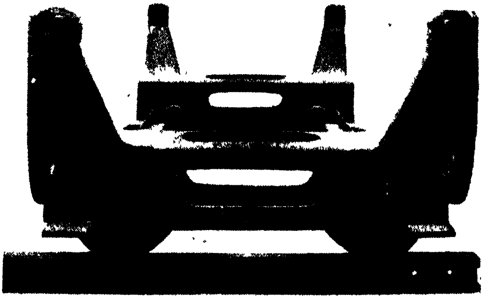

FIG. 92.—Tie tram of cast steel. Bails (not shown) must be provided to hold ties in place during treatment. (*The Wood Preserving Corp.*)

Live Rolls and Conveyor Belts.—Conveyor belts or power-driven rolls (*live rolls*) are used, in addition to hoists and cranes, for transporting wood at many plants. Such contrivances are particularly useful around incising machines, adzing and boring machines, and timber-framing mills, for moving timber from one operation to another. At least one plant uses a conveyor belt for bringing ties from the yard to the incising machine.

Tram Cars.—The tram cars, which are used primarily for transporting timber in and out of the treating cylinders, must be sturdily built in order to stand the severe usage to which they are subjected (3). The strongest trams are made of cast steel (Fig. 92) and are equipped with roller bearings, which facilitate their movement by greatly reducing the amount of tractive effort required; despite their higher first cost, they are said to be very economical because of the low maintenance. The older types, made of riveted and bolted structural steel (Fig. 93), are cheaper but require more repairs.

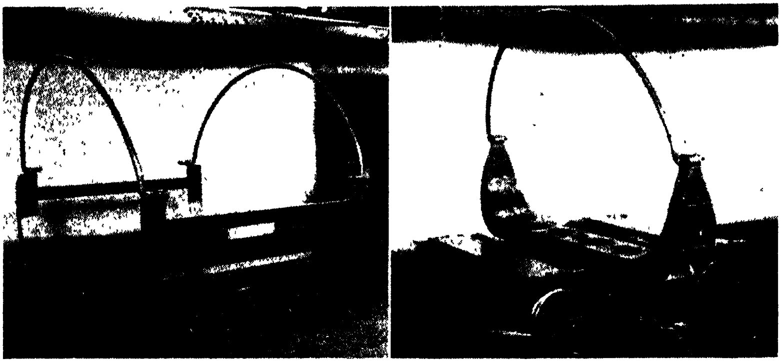

FIG. 93.—Tie tram (left) and bolster tram (right) of structural steel. (*Allis-Chalmers Mfg. Co.*)

Trams made to hold ties and short lumber have two pairs of arms, with bails to hold the load in place; those designed for poles, piles, and long lumber and timbers (*bolster trams*) have a single pair of arms attached at the center of the car, with the bolster so constructed that it can turn on a kingpin to accommodate the load on curved tracks. Two bolster trams are required to sup-

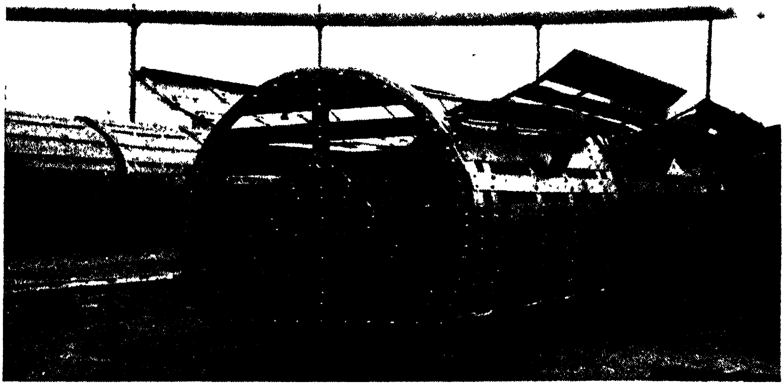

FIG. 94.—Trams used in creosoting wood paving blocks.

port a load of long timbers, one being placed near each end of the sticks. Trams that are used for paving blocks or other material in small pieces carry baskets made of perforated sheet metal, or suitable screens, which permit the free passage of preservative but confine the wood (Fig. 94).

Loading Areas.—When it is necessary to load out treated ties by hand, *loading docks* are provided to facilitate the work. These are formed by either elevating the tram tracks or depressing the railway tracks, so as to bring the former to about the level of the floor of the railway cars. When the loading is done by cranes or hoists, as is usually the case with poles, piles, and other heavy timbers, and often with crossties, it is not necessary to change the track levels and provide a special platform. It is still desirable, however, to concentrate all of the loading work in one part of the yard; if stationary hoisting equipment is used, such concentration is absolutely necessary.

Fire Protection.—The large volume of timber usually kept in the storage and seasoning yard constitutes a distinct fire hazard. It is customary to place fire hydrants and hose, as well as water barrels, at strategic points throughout the yard, to provide special fire lanes or runways for easy access to all points, and to have occasional fire drills to keep the plant crew in training. The fire pump may be located in the retort house or in a separate building near by. Insurance companies exercise considerable control over fire-protection arrangements.

ADDITIONAL EQUIPMENT

Depending upon the size of the plant and the character of the treatment, it is necessary to have more or less equipment, in addition to that described above.

Boiler Plant.—A boiler plant is required to furnish steam for heating preservatives, steaming green wood, operating electric generating equipment and pumps, and other purposes. Small plants, located near a convenient and dependable source of steam, may not need boiler equipment of their own, but larger plants are usually required to provide their own steam supply.

Electric Generating Equipment.—This equipment is needed for the operation of lights and motors, unless the plant is so located that it can purchase electricity economically. Electric motors are extensively used for the operation of pumps, compressors, woodworking machines, and a variety of other apparatus.

Centrifuges.—Since the percentage of water in the preservative oil must be kept within the specification limits, it is necessary to remove the surplus which results from the steaming operation in conditioning green timber, from leaky steam coils, and from other sources. Centrifuges, which operate in the same manner as ordinary cream separators, are used at some plants for this purpose. At other plants, the water is separated from the oil by settling in tanks, by heating the oil under vacuum in the treating cylinders, or by boiling off the water at atmospheric pressure in open tanks.

Track Scales.—These scales are frequently used when air-dry timber is treated, in order to determine the net absorption of preservative by weighing the wood just before it goes into the cylinder and immediately after it comes out. This method is not accurate for wood that is conditioned by the steaming-and-vacuum method, because of the change in moisture content of the wood during the steaming operation. Weighing is also not an accurate means of determining absorption when timbers are conditioned by the boiling-under-vacuum (Boulton) method, for there is considerable loss of moisture during the boiling period. In the treatment of green timber, weighing the preservative may give more accurate results than weighing the wood, but there are also chances for undetected errors in that method.

Tie-piling Machines.—While numerous machines and methods have been devised to reduce the amount of hand labor and the resultant cost involved in piling ties for seasoning or in loading them on treating trams from the seasoning piles (2, 8), none of them has been generally adopted, and hand labor is still almost universally employed. Cranes are used in some plants, however, for lifting bundles on and off the seasoning piles. They make it possible to pile the ties considerably higher than can be done economically by hand, and this is a definite advantage when yard space is limited.

Framing Machinery.—Machinery is necessary for the economical framing of timbers or the prefabrication of structures before treatment. Framing mills (Figs. 49 and 50) contain the usual machines for sawing, planing, boring, dapping, and shaping wood, together with live rolls for moving the timber about (8).

Special mills are required for the production of crossarms, paving blocks, and wood conduit, and portable machines are widely used for roofing, gaining, boring, and trimming poles (Figs. 51 and 52) and for boring large timbers.

Adzing, Boring, Incising, and Shaving Machines.—Adzing and boring machines are a necessity in practically every fully equipped tie-treating plant, while incising machines are commonly employed for preparing sawed Douglas fir timbers and cedar poles for treatment and occasionally for certain crosstie species. Pole-shaving machines are being used rather extensively for the preparation of southern pine poles. These several machines are described in some detail in Chap. V.

Buildings

While treating cylinders are occasionally left exposed to the weather, they are usually housed to avoid heat losses, as well as for the protection of the equipment and workmen. Practically all other stationary machinery about the plant is also under cover. Several buildings are usually required at a plant, for it is seldom possible to effect an economical arrangement of the plant offices and all the equipment under one roof.

Laboratories.—A laboratory is not only useful to the plant operation but is required by the specifications of large purchasers, in order that their inspectors may make analyses of preservatives and moisture-content determinations of wood. As a minimum requirement, the laboratory must contain all the chemicals, glassware, and equipment needed to make the standard analyses of the preservatives being used, and should also have a drying oven. Companies that do an appreciable amount of research find use for a much greater variety of chemical and physical apparatus and may even install a complete small-scale experimental treating plant in the laboratory.

Dry Kilns.—Kilns are not used extensively by wood-preserving companies, although they have been provided by some of the more progressive concerns. They will undoubtedly be used much more extensively, as their advantages and practicability become more widely appreciated. Dry kilns are necessary when lumber treated with water-borne preservatives must be delivered in dry condition within a short time. Much dissatisfaction has resulted from the use of salt-treated lumber that was insufficiently dried. The shrinkage, corrosion, and paint damage resulting from the use of such material have frequently created a prejudice against treated wood that is hard to overcome. Dry kilns must be properly designed and skillfully operated, if satisfactory results are to be obtained.

Shower Baths and Change Rooms.—Such facilities are commonly provided for the workmen. They encourage cleanliness and reduce the danger of occupational disease or injury by preservatives.

Treating-plant Design

While the installation of small treating apparatus for home use is not difficult for anyone thoroughly familiar with the treating operations, the construction of larger plants requires the knowledge and skill of engineers who have specialized in this field. Not only must the engineer plan for tanks and cylinders of adequate strength, but he must be familiar with the latest developments in methods of carrying out the details of the various processes and also be skilled in plant arrangement and layout. The efficient arrangement of a plant favors the smooth flow of timber and preservative through the various operations, avoids confusion and delays, and has a marked influence on plant capacity and treating costs.

There are a number of engineers who specialize in treating-plant design as well as companies that engage in the construction of treating cylinders and tanks. A finished treating plant, however, includes apparatus of great variety, produced by many different manufacturers. Some plant designers or manufacturers have given special attention to the development of small, simple, and relatively inexpensive pressure-treating plants for use by mining companies and other consumers of treated wood, who wish to treat their own material but whose annual requirements are not very, large. An informal list of treating-plant designers and builders may be obtained upon request from the U. S. Forest Products Laboratory at Madison, Wis.

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CHAPTER XI

METHODS OF PROTECTING WOOD OTHER THAN BY STANDARD PRESERVATIVE TREATMENT

While treatments with suitable preservatives will protect wood against the attacks of fungi, insects, and marine borers, such methods are sometimes too costly or inconvenient in their application to be practicable. Furthermore, the conditions under which wood is stored or used are frequently such that deterioration can easily be prevented by proper sanitation or by simple and relatively inexpensive control measures. Some of the protective methods involve the superficial application of chemicals; others provide mechanical barriers to attack; and still others are based on merely avoiding conditions that favor the development of the deteriorating agencies. The following discussions of the various protective measures are necessarily brief, and the reader is referred to the cited publications for more detailed information.

PROTECTION AGAINST DECAY

Any attempt to protect wood against decay, other than by impregnating it with toxic chemicals to poison the food supply, must be based upon maintaining a temperature, air supply, or moisture content that is unfavorable to the development of the wood-destroying fungi. Temperature control is obviously out of the question in all but a few highly specialized uses of wood, and much the same situation exists with regard to the air supply. However, piles and other forms of wood that are completely immersed in water, or buried deeply in the ground, contain so little air that they will last indefinitely. The most feasible method of control usually lies in reducing the moisture content of the wood below the danger point as quickly as possible and then keeping the material dry. The minimum moisture content at which wood can decay has not been definitely determined, but it is probably somewhat greater than 20 per cent (page 30).

PROTECTION OF LOGS AND TIMBERS

Logs should be removed from the woods and sawed into lumber and other products as soon as possible after cutting, especially during the seasons of the year when fungi (and insects) are active. When, for any reason, it is necessary to hold them in land storage at the mill, some measure of protection may be obtained by applying antiseptic sprays or coatings to the ends and barked portions of the logs (10, 14, 19), although the effectiveness of such treatments may be largely dependent upon the prevalence of wood-boring insects.* The logs may also be protected by keeping them in continuous water storage until they are milled.

Round timbers, such as poles, piles, posts, mine props, and other products with adhering bark, should be peeled promptly to facilitate surface drying; all timbers should be moved to the seasoning yard without undue delay. If early removal is not practicable, the timbers should be stacked on high skids on well-drained ground, where they will be exposed to the sun and active air circulation. The methods of piling used at both temporary and permanent seasoning sites should promote as rapid drying as is consistent with freedom from excessive checking (11). Sanitation of the seasoning yard is also essential to the protection of timbers and other forms of wood against decay.

PROTECTION OF LUMBER

The most satisfactory method of protecting lumber against decay is to kiln dry it green from the saw and then so store and use the material as to keep its moisture content always below the point required for fungus development. Kiln drying not only makes it possible to achieve rapid seasoning, but also affords an opportunity to sterilize any wood that already contains decay (page 35). This method of seasoning is used extensively by the larger softwood mills, particularly for drying the higher grades of lumber, and is also receiving greater attention at many of the hardwood and smaller softwood mills. When it is not practicable to kiln dry the lumber, it should be air seasoned under the best possible practice. (See discussion of air-drying practice in Chap. V.)

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* See subsequent discussion of protection against blue stain.

Chemical treatments, such as are advocated for preventing blue stain, have been found beneficial for protecting freshly cut lumber against decay (14), while steaming and such special piling methods as end racking and end piling have also proved effective when properly applied (19). All of these protective measures are intended as preliminary steps to the regular air seasoning of the wood.*

PROTECTION OF BUILDINGS

Most of the wood in houses and other buildings is kept so dry in normal service that it remains sound for an indefinite period. In such structures as these, deterioration by decay-producing fungi is usually limited to wood placed in contact with or near the ground. However, leaky roofs, windows, and plumbing, as well as condensation from water pipes and other sources, may often supply sufficient moisture to cause serious decay in localized areas. Most decay does not spread far beyond wood that has become damp, but the dry-rot fungi (page 31) have been known to work from moisture sources in basements up into the second stories of houses, destroying a considerable proportion of the woodwork.

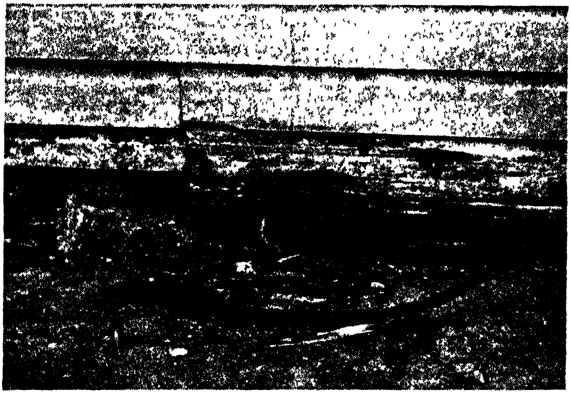

FIG. 95.—Decay in sill and lower siding in building, caused by placing wood in contact with ground.

The cardinal principles of good building practice, to avoid moisture accumulation and decay, may be summarized in the following seven rules:

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* See subsequent discussion of protection against blue stain.

1. *Place no untreated wood within* 18 *in. of direct contact with the ground.* (Fig. 95.) The wide variations in temperature, rainfall, prevalence of extremely destructive fungi, and availability of naturally durable woods in different sections of the country permit considerable latitude in the application of this rule. In warm, humid regions, 18 in. may actually be an inadequate height. In the colder and drier parts of the country, on the other hand, wood may be placed considerably closer to the ground, and naturally durable material may last a long time even in direct contact with the earth. In some localities, so far as decay is concerned, buildings may safely be supported on piers or posts of durable wood. The stated rule should always be observed, however, unless adequate local experience has definitely demonstrated that there is no risk attached to violating it. Whenever the design of a building requires that wood be placed so close to the ground that it will be subject to decay, or whenever there is uncertainty as to the safety of using untreated material in any particular location in a building, the wood should be impregnated with a suitable preservative.

2. *Avoid the accumulation of moisture from condensation, leaks, absorption from the soil, or other sources.* In many parts of the country, the water vapor in the air within the walls of a house may condense on the back of the sheathing or the underside of the roof during cold weather and even freeze there. When this happens, more water vapor moves into the wall space from within the house, and this, in turn, is condensed, until, if the process is continued long enough, the amount of moisture taken up by the wood may be sufficient to permit decay as well as to cause swelling and paint difficulties. This condition may be aggravated if the air in the house is artificially humidified and if the walls are insulated. Practical methods of preventing the accumulation of moisture from this source have not been fully developed, but much work is being done in this field, particularly in view of the modern trend toward extensive insulation and humidification of buildings.

During warm, humid weather, there may be so much condensation of moisture on cold-water pipes or on the flush tanks of toilets that a considerable quantity of water drips on to the woodwork beneath. This may raise the moisture content of walls or floors to such a point that the wood is liable to serious localized decay. Such difficulty may be avoided either by insulating the cold surfaces or by making some provision for preventing the condensed moisture from reaching the wood. During cold weather, water may condense on windowpanes in sufficient quantity to run down over the sash or sills and soak into the wood. The installation of storm windows will greatly reduce such condensation and thus decrease the danger of decay around the wall openings. The accumulation of moisture from leaks in roofs or around flashing, or from any other type of disrepair, can obviously be remedied by proper maintenance.

The absorption of moisture from damp soil may take place through concrete subfloors or porous foundations. Decay is frequently found in wood flooring laid directly on concrete subfloors that are in contact with the ground. Unless the concrete can be effectively waterproofed, it is advisable to treat the wooden flooring members with a suitable preservative. Furthermore, it is especially important that the concrete subfloor be thoroughly dried before the wood floor is laid over it. The ends of untreated girders, joists, and stringers should not be embedded in exterior walls or piers of concrete, brick, or stone unless adequate ventilation is provided to carry off the moisture that may reach the wood.

3. *Provide adequate ventilation beneath the building.* Special provision for ventilation should be made beneath all houses that are not provided with basements or in which the basements are so damp that the exposed woodwork will absorb considerable quantities of moisture from the air. It is important that the structures be supported on foundations of adequate height and sufficiently open construction to insure ample air circulation. The ventilators may be grilled holes left in otherwise solid foundations, latticed brick in selected sections of brick walls, or unenclosed or wood-latticed spaces between supporting masonry piers. In cold climates, it is desirable to install special vents which may be closed during the winter months to avoid unnecessary cooling of the ground floor. Dense bushes or other plants should not be placed directly in front of ventilators, as they will greatly reduce the effectiveness of these openings. Earth-filled porches and terraces are also conducive to decay and may lead to infection of

unprotected sills and other adjacent parts of the wooden framework. Porches elevated above the ground should be so built as to insure ample circulation of air beneath them.

4. *Remove all stumps and wooden debris from beneath or near the building.* Such wood tends to harbor decay-producing fungi (and insects) and increases the danger of infection in the building. Concrete form stakes left in place have very frequently provided the means of access by which decay (and termites) have been able to invade structures from the soil.

5. *Provide adequate soil drainage.* Every practicable step should be taken to see that rain water and melting snow are carried away from the building and that the drainage of the general area is sufficient to keep the ground beneath and around the structure dry. If the ground slopes toward the building, special grading may be required to divert the surface drainage.

6. *Use only wood that is entirely free from decay.* Material that has become infected in the seasoning or storage yard should not be installed in a building. While such lumber will usually remain sufficiently dry to prevent further deterioration, there is always the possibility of progressive decay if sufficient moisture becomes available from leaks or other sources. Care must also be taken to see that all lumber is properly protected from decay during temporary storage at the building site, and under no conditions should it be close piled directly on the ground for any length of time. Blue-stained lumber should be carefully inspected for decay.

7. *Use only wood that is reasonably dry.* Inadequately seasoned lumber or material that has become thoroughly wet through exposure to rain may not only give trouble by shrinking as it dries out after installation, but may also become seriously infected with decay if drying proceeds slowly. Wet wood is particularly apt to cause trouble if it is covered with materials that prevent or retard seasoning.

Although the proper time to take precautions against the deterioration of a building by wood-destroying fungi is when the structure is erected, most people become concerned about decay only after the disintegration of the wood has progressed to a noticeable extent. But whether a new structure is being built, or an old one repaired, the same rules should be observed. In some cases, it may be sufficient to replace the rotted wood with treated material or with wood of high durability, at the same time correcting, so far as possible, the conditions that led to the decay. But it will usually be safest and cheapest in the long run to remodel the building, as may be required, in order to incorporate all of the provisions recommended above for new structures.

PROTECTION AGAINST TERMITES

Since **subterranean termites** always maintain a soil contact, permanent prevention or remedy of their damage in buildings can be effected by providing complete insulation of all woodwork from the ground. In general, the foregoing recommendations for avoiding decay are also effective for termite control in most sections of the country (16). Untreated wood placed in contact with or close to the soil is readily invaded in regions in which subterranean termites are plentiful, and the insects often build covered runways over foundations and other impenetrable obstructions to reach floor joists or other wood (Fig. 15). Not infrequently the termites build unsupported tubes up from the soil, but wood that is not closer than 18 in. is usually safe from attack in this manner (16). Since damp wood is more susceptible to attack than dry material, adequate ventilation should be

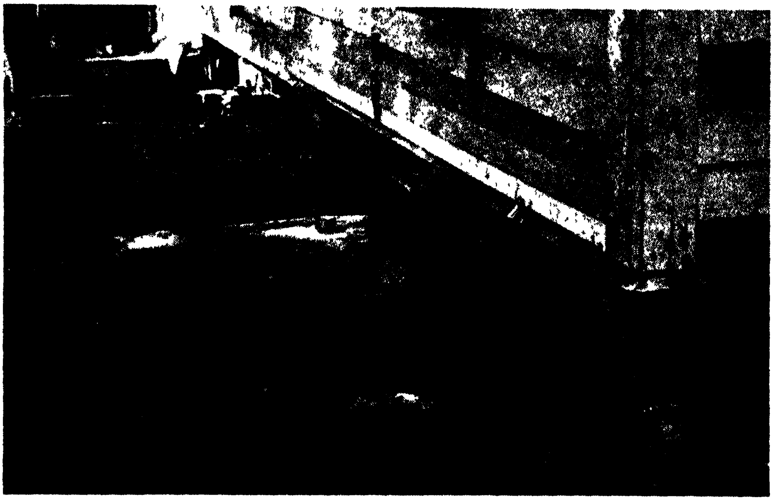

FIG. 96.—Termite shield over brick foundation of a house. Note projections for shielding cellar hatchway. (*Connecticut Agricultural Experiment Station.*)

provided beneath buildings, and moisture accumulation from all sources should be avoided. Old stumps, roots, and waste wood of all kinds are attractive to the termites, and disposal of such debris reduces the possible sources of infestation. Concrete form stakes may afford particularly favorable opportunities for the insects to enter buildings, and should always be completely removed. Buildings should be so constructed that all parts near the ground are readily accessible for inspection.

In regions where subterranean termites are very active, it is desirable to install metal shields (Fig. 96) as barriers to the movement of the insects from the ground to the woodwork of buildings (2, 16, 20). These shields consist of sheets of copper or other noncorrosive metal, which are inserted between the foundation and the wood framework. They should extend downward and outward at an angle of about 45 deg. for a distance of at least 2 in. from both sides of the foundation. The metal should be continuous, with all joints soldered or tightly crimped, to avoid any possible opening through which the termites might pass. All pipes, conduit, or other facilities entering the building should be provided with tight-fitting collars of the same character (Fig. 97). Failure to fit the shields properly or to cover completely all possible entrances to the woodwork may afford the termites access to a building. In heavily infested localities, it is desirable to install shields even when all woodwork near the ground is treated, for otherwise the termites may build runways

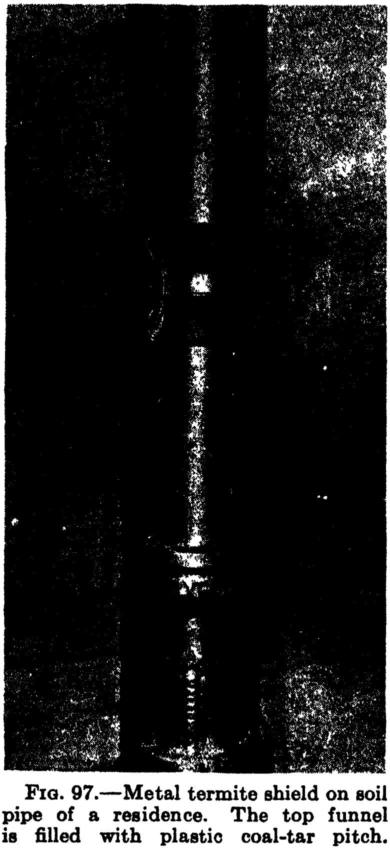

FIG. 97.—Metal termite shield on soil pipe of a residence. The top funnel is filled with plastic coal-tar pitch. (*Connecticut Agricultural Experiment Station.*)

over the surface of the treated material or along pipes that enter the building, and thus reach the untreated wood above.

Subterranean termites may also gain access to the woodwork of buildings through existing cracks or hollows in masonry walls or by excavating channels in lime mortar (9, 16, 20). Hollow masonry units should not be used for foundations unless special protection is provided by a solid capping of reinforced concrete or a termite shield. Ordinary lime mortar should be avoided, all masonry being laid solid in cement mortar (one part Portland cement and three parts sand; hydrated lime not to exceed 10 per cent of the weight of the cement may be added). Termite shields should extend completely over the foundation walls, unless these are of heavy concrete or masonry which will remain free from fissures of any sort.

In repairing a building that has been damaged by subterranean termites, all of the seriously infested wood should be removed; all leaks or other sources of moisture eliminated; and direct access between soil and wood completely cut off. Termites left in the woodwork cannot survive without an adequate supply of water.

Dry-wood termites are so limited in their distribution and do so little damage to buildings, in comparison with subterranean termites (page 64), that it is not customary to make special provision to protect buildings against them. Attack is much more difficult to avoid than in the case of the subterranean forms, since the dry-wood termites do not require access to the soil or a special supply of moisture. However, such measures as screening all openings, promptly painting all exposed wood in new buildings, insuring tight construction to avoid crevices in which the insects may start their activities, and covering the material being used on the construction job, particularly during the swarming season, are recommended as being helpful in preventing infestation (9). Attack may be avoided, of course, by using treated wood throughout a building.

When buildings are found to be seriously infested with dry-wood termites, all badly damaged wood should be replaced. If such replacement is not practicable, further damage may be avoided by blowing poisonous dust, such as finely divided Paris green, arsenical dust, or sodium fluosilicate, into each nest (9).

PROTECTION AGAINST LYCTUS POWDER-POST BEETLES

The damage done by the larvae of the *Lyctus* powder-post beetles (Fig. 17) is largely confined to the seasoned sapwood of lumber and such manufactured products as furniture, tool handles, shoe lasts, agricultural machinery, flooring, trim, and similar items, which are made from susceptible hardwood species (page 67). These insects seldom attack products that are continually being handled and moved about, but work mainly in material that is left undisturbed for long periods of time.

The principal precautions to be observed in preventing *Lyctus* attack are proper sanitation, periodic inspection, and the avoidance of long storage periods (15). Susceptible lumber or manufactured products should be stored only in structures built of material that is immune to attack, and no old stock or waste wood should be allowed to accumulate in the shed or bin. The wood should be piled in such a manner that it is readily accessible for careful inspection, and this should be made every few months. Since the insects work rather slowly, prompt detection and disposal of damaged wood will prevent serious spread of attack. The older supplies of material should be used up first, and unnecessarily large stocks should not be accumulated.

Deterioration that has started in storage may continue after the wood is placed in service, especially when it is used for items such as house trim, flooring, and furniture. Consequently, the manufacturer should make certain that the wood contains no living insects when it leaves his hands. Seriously infested wood should be promptly burned, while suspected stock and valuable material that is only partially damaged can be sterilized by thoroughly heating the wood in live steam at a temperature of not less than 135°F. or by kiln drying it at 180°F. (15). The heating period required depends upon the size and moisture content of the pieces of wood as well as upon the heating medium; steaming is more promptly effective than dry heat at the same temperature.

While sterilization by heat will kill the insects already established in the wood, it will not provide immunity from subsequent attack. Permanent protection may be obtained in uninfested finished products by coating all surfaces with paint, varnish, linseed oil, or any other suitable material that fills the pores and fine cracks; in this way, the adult beetles are prevented from depositing their eggs in the coated wood. The wood can also be protected by being impregnated with a toxic chemical, but this is seldom done to guard against *Lyctus* attack.

PROTECTION OF PILING AGAINST MARINE BORERS

Although heavy absorptions and deep penetrations of coal-tar creosote unquestionably afford the most generally satisfactory and economical protection to wood piles used in marine-borer-infested waters, other methods have also been employed from time to time. These involve the use of various types of exterior coverings, which act as barriers to the entrance of the marine borers into the wood (4, 5).

Bark.—One of the oldest methods advocated for protecting salt-water piling involves merely leaving the bark on the timbers when they are placed in service. This natural covering seems unattractive to the marine borers, and they do not enter it so readily as solid wood. One very serious difficulty with this type of protection, however, is that the bark is seldom, if ever, intact over the entire surface that is exposed to attack. The bare spots, left where branches are trimmed off or where patches of bark are knocked off in handling or driving the piles, afford unobstructed points of entrance to the borers. Attack spreads from these foci and may be severe enough practically to destroy the utility of a pile before the more adequately protected parts are seriously damaged. However, even piles that are carefully selected and handled so as to avoid bare spots, or that have the exposed wood protected in some other way, will probably not last more than one or two years longer than comparable peeled timbers (5), for the softening action of the water and the abrasive effect of driftwood and waves soon cause patches of bark to fall off. Piles protected by bark alone should be employed only in temporary structures or where more adequate protection is impracticable.

Nails.—The use of nails, or *scupper nailing*, as it is sometimes called, as a means of protecting wood piles originated in ancient times and has persisted in a small way down to the present, having been used frequently in Germany (12) and Denmark. The method involves driving flat-headed nails into a pile, over the entire section that will be exposed to the borers. Although the nails are usually spaced very close together, it is not possible to form a complete armor against the shipworms, the larvae of which are so small that they can find lodgment in minute openings; this type of protection may be somewhat more effective against the attacks of crustacean borers, although this fact has apparently not been demonstrated. The formation of iron rust in the wood between the nails is believed to have some protective value, although the San Francisco Bay Marine Piling Committee reported (5) that such rust does not always exclude the borers and cannot be safely relied upon.

The Charleston Dry Dock and Machine Company is reported (4) to have driven 600 "scupper-nailed" yellow pine piles in 1918. These were protected with roofing nails about 1 in. long, with heads about ⅜ to ½ in. in diameter and spaced ½ in. apart. While no detailed record of the results obtained has been published, the piling apparently gave appreciably longer service than would be expected from unprotected timber.

The chief disadvantage of this method of protection, aside from its lack of reliability, is the cost of the labor required to drive the nails. Another possible objection is that decay, which is not retarded by the nails, may cause such rapid deterioration of the above-water parts of the piles, especially when nondurable species of timber are used in warm, humid climates, that the full service life of the lower parts is not realized.

Sheet Metal.—Metal coverings were employed in ancient times to protect the bottoms of wooden ships, but their application to piling was apparently a development of the nineteenth century. Metal-covered wood piles are reported (4) to have been used in England as early as 1833, and no doubt there were prior installations. Copper has been the preferred material, because of its resistance to corrosion, but zinc and an alloy of copper and zinc, known as *yellow metal*, or *Muntz metal*, have also been used frequently, although they usually do not last so long as copper. Sheet iron corrodes too rapidly to afford much protection.

It is necessary that the piles be prepared before driving. Best practice requires that all knots and other projections be removed and the surface made as smooth as practicable, after which an even coating of burlap or felt, saturated with asphalt or a similar material, is applied. The sheet metal is then nailed tightly over the entire surface that will be exposed to borer attack, being extended a few feet below the mud line to avoid exposure of unprotected wood, in the event that the mud is scoured away from the base of the pile after installation.

Records of very long service life have been reported for metal-covered wooden piles. Timbers covered with sheet copper and installed in 1877, in a wharf constructed in the harbor of Tacoma, Wash., by the Southern Pacific Railway Company, were said to have been in good condition when the structure was removed in 1898. Forty-four of these piles were redriven in a Northern Pacific Railway Company bridge in 1900 and in 1922 were still in sound condition (4). On the other hand, metal-covered piles have frequently had a service life of as little as 10 years and occasionally have failed in a much shorter period.

The sheet metal does not protect the tops of piles from decay, of course, but so long as the covering remains intact and tightly fastened to the timbers, the borers cannot get through to the wood. However, the metal may be damaged to such an extent by storms and driftwood, particularly when it is somewhat weakened by corrosion, that the borers are able to invade the wood and soon destroy the piles. The use of sheet copper presents an added difficulty in that it may be stolen by harbor thieves. In some cases, storms or currents have scoured the mud away from the bottoms of the piles sufficiently to expose unprotected wood. Because of these shortcomings, the use of sheet-metal coverings for pile protection has been almost entirely discontinued.

Cast-iron Pipe.—Cast iron corrodes very slowly and usually has such a long life, even in sea water, that it has been used to some extent for protecting wooden piles. One method of protection involves the use of half-pipe sections of such size and shape that they can be conveniently bolted around the piles after these have been driven. The pipes are then forced deeply into the mud, to protect the base of the piles in case of scour. After a pipe is placed, the space between the wood and the metal is usually filled with sand or cement mortar. So long as the joints remain tight and the pipe retains an unbroken surface over the underwater part of the pile, the marine borers are unable to invade the wood. The chief source of trouble when these casings are used lies in the possibility of the mud being scoured away from the base of the piles, below the iron. The upper parts of the piles are also subject to decay. The principal disadvantage of this method of protection is its high cost. The use of cast-iron pipes over heavily creosoted piles would provide the greatest assurance of long life in waters seriously infested with marine borers, but the expense of such construction would be justified only in highly important structures, in which the necessity of avoiding repairs was very great.

Vitrified-clay Pipe.—Casings of this material have been used in the same way as cast-iron pipe but with less success, owing to their fragility and the ease with which they can be broken by storms and driftwood. Examples have been reported of very long life in quiet water, but there is also record of one installation in which the casings were broken within a month after they were placed (4).

Concrete Casings.—Concrete casings have been used both for the protection of new piles and for the repair and protection of timber that has already been attacked by marine borers. There are many possible variations in the method of applying the concrete (5), but only a few will be mentioned in this discussion. The main forms include precast pipe sections, gunite casings, and casings poured around the pile before or after driving. With all types, successful results are dependent upon getting complete, unbroken coverage of the pile with a concrete that is both strong and durable in sea water. Reinforcement is necessary for high strength; but since the concrete shell is thin at best, there is always a possibility that sea water may reach the reinforcing and cause corrosion of the iron, spalling or cracking of the concrete, and the ultimate breakdown of the protective covering. Many casings have failed in this way. On the other hand, there are records of installations in which concrete casings of one type or another have given very satisfactory service. Pile protection with any form of concrete is expensive, however, and suitable only where the high investment can be justified.

The *Koetitz pile armor*, which has been used rather extensively in the San Francisco Bay region (5), consists of a precast, hollow, reinforced-concrete cylinder, having a usual minimum shell thickness of from 2½ to 3 in. and sufficient diameter so that it can be slipped over previously driven wooden piles. By driving the piles with the large end down, the concrete cylinders can be of smaller diameter than when it is required to slip them over the large end of the timbers. After the casings are placed, the space between them and the pile is filled with sand or grout. Although quite expensive, this form of protection has generally given very satisfactory service.

The *gunite method* of coating piles with cement (Fig. 98) has been used to some extent in this country. Outstanding is an installation of over 1400 gunited Douglas fir piles made at Tacoma, Wash., in 1922 (3). The peeled piles used on this job were first covered with a 2-in.-square wire-mesh reinforcing, held ¾ in. from the surface of the wood, and then coated to a depth of from 1½ to 2 in. with a cement-sand (1 to 2½) mixture, applied by means of a "cement gun." In order not to damage the coating in placing the timbers, the piles were jetted down, using only the weight of the hammer and not driving with heavy blows. In this particular installation, the cost of the gunited timbers was about twice that of creosoted piles. A diver inspection was made in 1936, and all of the piles were found to be sound, with the concrete in excellent condition.

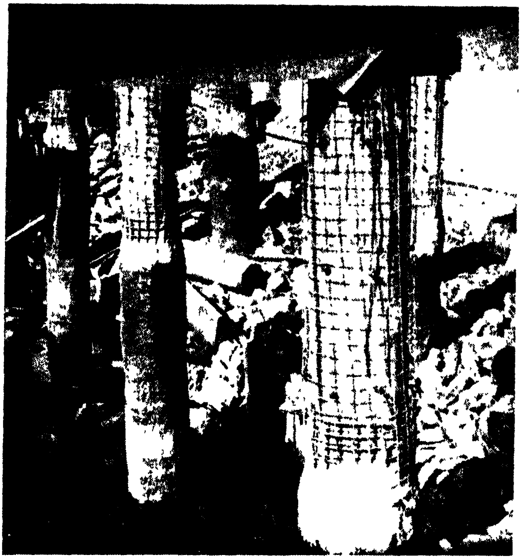

FIG. 98.—Partially completed gunite protection to wood piles in place.

The *Camp process* of pouring concrete casings around piles already in place was employed to a considerable extent in the San Francisco Bay region a number of years ago (5). Collapsible, sectional forms (Fig. 99) made of tongued-and-grooved wood staves were fastened together with iron lock wedges to make a completed cylinder around the pile. The sections were only 3 ft. long and could thus be used beneath wharf floors or buildings without interfering with the normal use of the structures. The section that constituted the lower end of the completed form was provided with a metal-finger canvas arrangement which fitted closely around the pile to prevent the concrete from falling through. This bottom section was placed around the pile above the water line, filled with concrete, and lowered into the water by cables until there was room for a second section on top of it. The second section was then bolted to the first and filled with concrete, after which both were lowered enough to permit the placement and filling of a third section. This was continued until the pile was covered from below the mud line to the desired height. After allowing the concrete to set for a day or two, the forms were removed by pulling the lock wedges, which were attached to a chain running up the side. By pouring the concrete above water and then lowering it into place, it was not necessary to make the

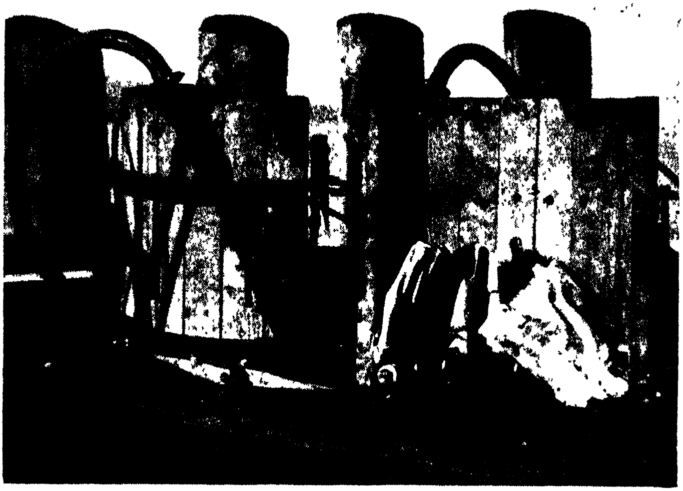

FIG. 99.—Lower forms used in Camp process of pouring concrete casings around wood piles. Note metal fingers and canvas to keep concrete from dropping through. (*San Francisco Bay Marine Piling Committee.*)

form entirely watertight and to pump it dry before filling with concrete, as must be done with other methods of casting the casings in place. The Camp process was costly to apply; but when the work was well done, very good protection is said to have resulted, although no definite service data are available. It was considered more suitable for piles in shallow than in deep water, owing to the tendency of the concrete mixture to separate as it slid down the pile. Some of the recorded failures were known to have been caused by the concrete shell being too thin on one side, as was very apt to be the case on leaning or crooked piles; by some irregularity of the pile or the presence of heavy marine growths; or by the development of flaws in the concrete, such as resulted from air bubbles, separation of the aggregate, and other causes.

Paint Coatings.—Paints of one kind or another have been vigorously promoted at various times for protecting wooden piles against marine borers. These have usually consisted of asphaltic or bituminous materials, but various other substances have also been used. Some of these paints were specially treated, so that they would remain viscous and elastic instead of hardening with age; others contained hard materials designed to impede the progress of the borers, or poisonous compounds intended to kill them; while still others were combined with burlap or some other fabric. Paint coatings are always rather fragile and, therefore, easily broken or worn away by wave action or drifting objects as well as deteriorated by continuous exposure to sea water. For these reasons they are suitable for use only in very quiet water and even there afford only very temporary protection—possibly from 6 months to 2 years.

Paint-and-batten Methods.—A considerable variety of paint-and-batten coverings have been used. These consist of heavy paints, used in combination with fabrics, roofing paper, wire mesh, or other reinforcements and protected from abrasion by wood strips, or battens, which are nailed or wired in place (Fig. 100). The covering is attached to the piles before driving, being applied only to the part of the timbers that will be exposed to borer attack.

Although there have been many variations in the materials employed, as well as in the methods of applying them, the following represents a typical procedure (5): The bark was removed from the part of the pile to be protected, and all knots and other irregularities were smoothed off. A coating of a thick, viscous paint was first applied, followed by a layer of asphalt-saturated burlap or felt and a second heavy coating of paint. A layer of close-fitting redwood battens, each about 2 in. wide and ½ in. thick, was then securely nailed in place, after which a final coating of paint was applied, filling all the cracks and leaving a smooth surface.

With regard to the efficacy of the paint-and-batten methods, the San Francisco Bay Marine Piling Committee estimated (5) that: "If piling is properly treated by these processes and is not damaged by careless handling, and if its use is limited to locations protected against serious storm action, a life averaging from five to eight years may be obtained."

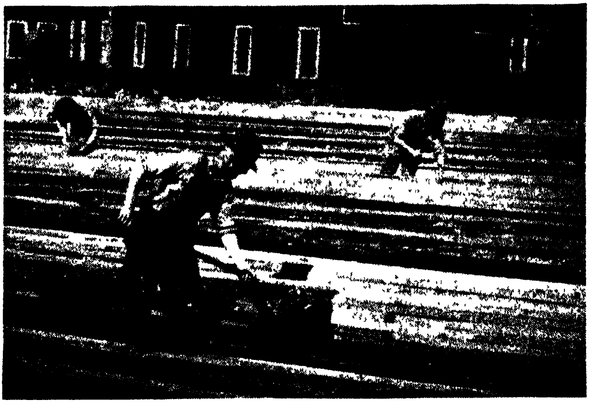

FIG. 100.—Piles protected by paint-and-batten method. (*San Francisco Bay Marine Piling Committee.*)

PROTECTION AGAINST BLUE STAIN

The fungi that produce blue stain (sap stain) may attack sapwood in various stages of manufacture, from the log to the finished product in storage or use. Consequently, the preventative measures may need to be varied somewhat, in accordance with the form of material requiring protection, although the basic principles of control are the same in all cases.

PROTECTION OF LOGS

If logs are held in the woods or in land storage for long periods during warm humid weather, blue stain (and also decay) may invade the wood (Fig. 12) to such an extent as to cause serious loss. The best way to avoid such deterioration is to saw the logs into lumber as soon as possible after the trees are cut; but that is not always possible, and sometimes several months must elapse between the felling and sawing operations. When the necessary facilities are available, the logs may be protected by storing them under water. Complete submersion is necessary, however, as any wood that floats above the water will be susceptible to staining.

When water storage is not available or practicable, the logs may be protected for a month or two by promptly spraying or otherwise coating them with a suitable material on the ends and at all places where the bark has been displaced. Coatings consisting of a 10 per cent solution of cresylic acid in kerosene or crude petroleum, or in filled hardened gloss oil, have given fairly good results in experimental work. The kerosene solution gave good protection for about three or four weeks to red gum logs stored in the woods, while the hardened gloss oil was effective for one to two months and also decreased end checking (19). The gloss-oil coating is somewhat more expensive than the kerosene solution and more difficult to use, since it cannot be sprayed on the wood but must be applied with a brush. Scheffer and Chapman (14) were able to reduce the staining of stored hardwood logs very materially by spraying the exposed wood with a 0.1 per cent solution of ethylmercury chloride (2 per cent solution of *Lignasan*) or with a 5 per cent solution of sodium tetrachlorphenoxide (*Dowicide H*). A mixture of creosote and petroleum has also been reported as effective (10).

While none of these chemical treatments gives complete protection to the logs, they greatly reduce the amount of staining. Further study is needed, however, to explore the possibilities of spray and brush treatments, and to develop chemicals that will be sufficiently economical and effective to induce their general acceptance.

PROTECTION OF LUMBER

It is less difficult to protect lumber from blue stain than it is to protect logs, because the lumber is not only less bulky but is also usually concentrated at mills where it is possible to take advantage of the convenience and low cost of mechanized handling. As with decay protection, rapid drying affords the simplest method of control, and dry kilns have been found to be particularly advantageous in producing lumber free from fungus stain. The results obtained in air seasoning are quite variable, since the drying rate is dependent upon the weather; during protracted periods of warm humid weather, freshly cut lumber seasons so slowly that staining is almost inevitable in untreated sapwood material.

A number of methods have been devised, as preliminary steps to regular air seasoning, in order to hasten the early stages of drying or to protect the wood against stain until the moisture content of the surface layers can be reduced below the minimum required for infection. These include steam treatments, chemical dips, and special forms of end piling.

Steam Treatments.—Freshly cut lumber, and especially sap gum, has been quite frequently steamed in the past at certain mills in the South, although little use is made of this practice at present. The purpose of the steaming is to warm the surface layers of the wood, so that the outer shell will dry out rapidly when the lumber is subsequently air dried. The treatment is applied in closed steel cylinders or in steam boxes or kilns, and the temperatures vary over wide limits, often reaching as high as 180 to 212°F. Upon the completion of the steaming period, the lumber should be piled for air seasoning without undue delay. It may be desirable to cool the wood for a brief period before stacking it, in order to avoid too rapid surface drying and resultant surface checking. The lumber should not be bulk piled for even a short time, however, or the drying effect of the treatment will be lost. Steaming at high temperatures and for sufficiently long periods also sterilizes the wood, killing all staining and wood-destroying fungi that may be present. This effect is only temporary, however, and the wood may be reinfected as readily as unsteamed material, if it is exposed to conditions that favor fungus growth. (6, 19.)

Chemical Treatments.—Since 1905, a great deal of experimental work has been done in the United States in developing chemical dips that would prevent, or at least retard, the development of blue stain until lumber could be air dried sufficiently to be immune from attack (6, 21). It has long been known that mercuric chloride is highly effective for the purpose, but the price, poisonous character, and corrosiveness of this substance have prevented its general use, although it has been employed to some extent in Europe. Sodium bicarbonate was used as early as 1905, and in 1911 Weiss and Barnum (21) recommended 5 to 10 per cent solutions of this chemical as most effective for commercial work. A mixture of sodium carbonate and sodium bicarbonate was also advocated (6). Soda dips were rather extensively used for a number of years and did much to reduce the staining of lumber, but they frequently failed to give good protection, especially during warm rainy weather, and also imparted an often objectionable yellow color to the wood. For best results it was necessary to heat the solutions, but temperatures in excess of 160°F. were to be avoided, because of the danger of chemical breakdown above that point.

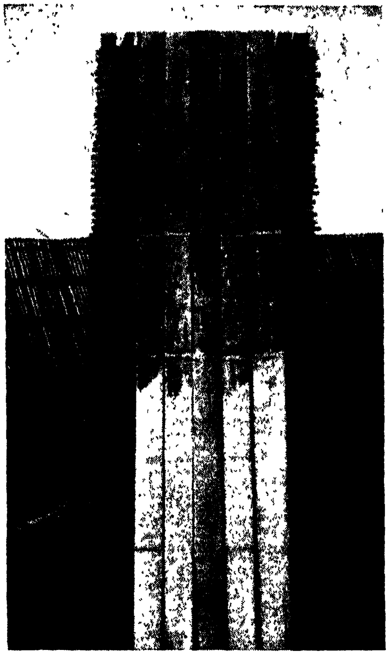

FIG. 101.—Effect of chemical treatment in preventing blue stain. The lower half of each board was dipped in blue-stain preventive, and the other half left untreated. Note heavy blue stain on untreated end. (*U. S. Bureau of Plant Industry.*)

Within the last 10 years, considerable progress has been made in the development of new chemicals for blue-stain prevention (Fig. 101). The experiments of the U. S. Bureau of Plant

Industry, made in cooperation with the Forest Service and with lumber producers and chemical manufacturers, have demonstrated that some of the more moderate-priced of these substances are far more effective than the sodium carbonates, and the lumber industry is now using several of them quite extensively. In summarizing these investigations, which extended over a period of several years, Scheffer and Chapman (14) report that good results were obtained with

> . . . borax, ethylmercury chloride (*Lignasan*), sodium tetrachlorophenoxide (*Dowicide H*) and phenylmercury acetate on hardwoods, and ethylmercury chloride and sodium 2-chloroorthophenylphenoxide on pine. Ethylmercury chloride was . . . the only single chemical effective on both pine and hardwood material, although a combination of sodium tetrachlorophenoxide and sodium 2-chloroorthophenylphenoxide (*Dowicide P*) was found to give similar and equally satisfactory results.

The borax was used in 5 per cent solution, while the other chemicals named were used in concentrations of 1 per cent or less. Tests have indicated that it is not necessary to heat these solutions to obtain effective control.

The most common method of applying these new stain preventives is to provide a vat of unheated solution, through which the lumber is carried mechanically, immediately after being sawed. Another method, which is more suitable for large timbers than for smaller material, is to pass the wood on rollers through a series of sprays which coat all the surfaces thoroughly with the chemical solution. If the mill is so small that it is not practicable to install suitable mechanical dipping or spraying equipment, the lumber may be immersed by hand, although the labor cost is high.

Since most of the chemicals now employed for stain prevention are highly toxic, and some of them may have a severe irritating effect on the skin, it is important that every practical precaution be taken to protect the workmen who handle the chemicals or the freshly dipped wood. No difficulty is experienced after the treated wood has been seasoned, however, for the troublesome chemicals either volatilize and gradually disappear during the drying period or are changed into substances that are not dangerous.

While the modern sap-stain preventives are definitely superior to those in earlier use, they are by no means "foolproof," and the protection they afford is only temporary at best. The subsequent air seasoning should be carried on under sanitary conditions, and the lumber piled to facilitate rapid drying, in order that the moisture content of the surface layers may be reduced as quickly as possible below the minimum point required for infection. Freshly dipped lumber should also be protected from heavy rains, to prevent the chemical from being washed off the surface.

Various attempts have been made to devise surface treatments that would prevent stains and other wood-inhabiting fungi from infecting railway ties, poles, piles, and similar products during seasoning or storage, but the results obtained to date have not been very favorable. These large products season so slowly that they are usually susceptible to fungus attack for a much longer period than lumber. Consequently, they require a more thorough treatment than is needed for lumber, thus increasing the expense of the protection.

Special Piling Methods.—End racking and end piling are sometimes used as preliminary steps to normal flat piling, in air seasoning such hardwoods as sap gum, yellow poplar, magnolia, basswood, cottonwood, and sap maple. Both methods are designed to increase the rate of initial drying of lumber and thus decrease its liability to staining (6, 11, 19).

End racking consists of piling the lumber on edge, in the form of an X or an inverted V. For best results, the lower ends of the boards should be raised off the ground on foundations and well spaced; the individual pieces should be separated by stickers at the point of crossing, which should be well toward the upper ends of the boards. During dry weather, several days of such seasoning will be sufficient to reduce the moisture content of the surface layers of the lumber below the critical point for staining. This method requires a large amount of yard space, involves extra handling, and may result in considerable warping and end checking, unless the boards are taken down and flat piled as soon as these defects begin to appear.

End piling gives the same effect as though the lumber had been flat piled in the usual manner and then tipped up on end. This method gives better support to the boards than end racking and thus renders them less subject to warping, but it does not result in such rapid drying. In fact, from the point of view of rate of seasoning, there is considerable question as to the advantage of end piling over normal flat piling.

PROTECTION OF FINISHED PRODUCTS

Blue stain may develop in finished products, if the wood becomes wet and remains so for considerable periods of time, either while the items are awaiting use or while they are in actual service. The only sure way to avoid such deterioration, aside from impregnation with preservatives, is to keep the wood dry. The stain treatments applied to green lumber do not afford permanent protection; and, furthermore, since the chemicals are surfaced off during the manufacturing processes, they are of no value in protecting the finished articles. Coatings of paint or varnish are ineffective, except in so far as they assist in preventing absorption of moisture by dry wood. Stain may often be found beneath varnish or breaking through paint, especially at the joints in the lower rails of window sash.

PROTECTION AGAINST MOISTURE

A great deal of the difficulty experienced with wood products in service can be traced to changes in their moisture content. Any economical treatment or method of protection that would prevent these moisture changes and not have an adverse effect on the properties of the wood would be of immense value, since it would eliminate shrinking, swelling, warping, grain raising, checking, weathering, loosening of joints, and even stain and decay. Unfortunately, no practical method is known for preventing changes in the moisture content of wood in normal service. Numerous proprietary products are claimed to "moisture-proof" wood, but even the best of these are only partially effective. It is also commonly believed that coatings of linseed oil or other oils or waxes accomplish this desirable purpose, but that belief is erroneous. On the other hand, complete immunization to moisture changes is not usually required, and much can be accomplished by drying wood to the correct moisture content before use and by applying the partially effective coatings and treatments now available.

The changes that occur in the moisture content of wood in service depend upon the conditions under which the material is used. Wood that is exposed to the weather or set in the ground comes in contact with liquid water and hence can absorb large amounts of moisture. Products used indoors, such as furniture, fixtures, flooring, and trim, are rarely, if ever, in contact with liquid water while in service but are surrounded by air that is constantly changing in relative humidity. Since wood is a hygroscopic substance and tends to give off or take on water vapor until it comes into equilibrium with the surrounding air, these changes in atmospheric humidity produce a continual fluctuation in the moisture content of the wood. Figure 102 shows the relation of the equilibrium moisture content of wood to the relative humidity of the surrounding air at three different temperatures.

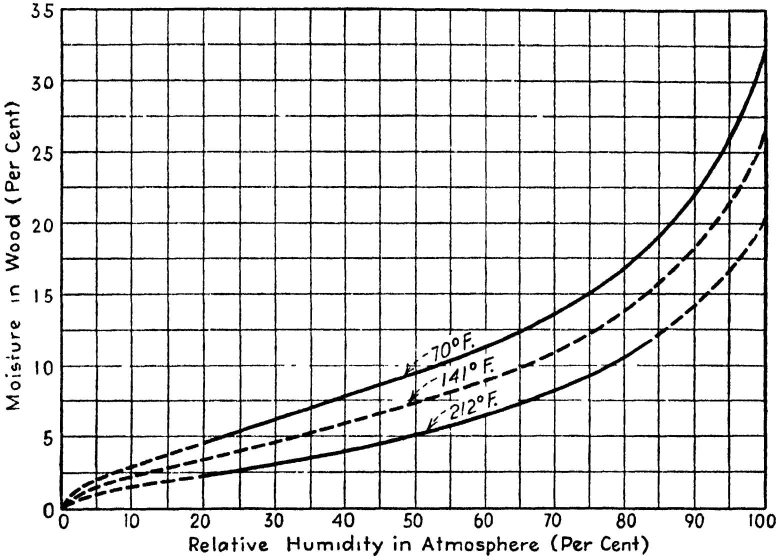

FIG. 102.—Relative humidity–moisture content relations of wood. (*U. S. Forest Products Laboratory.*)

The maximum range in the moisture content of wood, which results from variations in atmospheric humidity, is fairly restricted in many types of service. In such cases, shrinking and swelling may be minimized by drying the wood to a moisture content about midway between the extremes that it will attain when placed in use. For example, Peck (13) found that the average range in the moisture content of wood within houses in the dry southwestern states is about 4 to 9 per cent; in the damp southern coastal states, about 8 to 13 per cent; and in the rest of the United States, about 5 to 10 per cent. Consequently, wood trim, furniture, and similar products, if installed at moisture contents of 6, 11, and 8 per cent in these respective sections of the country, will not normally change more than 2 or 3 per cent from the average, with the result that the accompanying shrinking and swelling will be kept very low. In the same study, it was found that the optimum average moisture content for satisfactory service of sheathing, framing, siding, and exterior trim of houses in the designated regions is about 9, 12, and 12 per cent, respectively.

IMPREGNATION TREATMENTS

Various attempts have been made to devise impregnation treatments that would effectively reduce, if not entirely eliminate, the shrinking and swelling of wood in service. Most of these methods may be classed as *moisture retarding*, since they have as their immediate objective a reduction in the normal moisture changes that accompany exposure of wood to water, to the weather, or to variable atmospheric humidities. Some of the treatments, however, are primarily *shrinkage retarding*, being designed to reduce the amount of shrinking or swelling that accompanies a given variation in moisture content rather than to decrease the actual amount of moisture change.

Moisture-retarding Treatments.—Although no impregnating material has yet been found that will actually "moisture-proof" wood, certain substances are known to retard the rate at which its moisture content changes with variations in atmospheric humidity and also to reduce the rate of absorption of liquid water. Paraffin wax is moderately effective in this respect and is probably the most frequently employed for the purpose. Its usefulness is limited, however, as other finishes cannot be satisfactorily applied over paraffined wood, and also because the wax melts or softens when exposed to sunshine or other moderate temperatures. Wiertelak (22) found that impregnation with paraffin wax retarded the absorption of water or acid solutions to a noticeable degree but not enough to give substantial protection to wood that is continuously in contact with such liquids. Little information has been published concerning the moisture-retarding effectiveness of other waxes and of oils, although it is known in a general way that the rate of moisture change can be reduced by about one-quarter to one-half by impregnating wood with such substances.

Shrinkage-retarding Treatments.—Stamm (17) has demonstrated the possibility of greatly reducing, if not entirely preventing, the shrinking and swelling of wood with changes in moisture content, by impregnating it with substances that enter the fine capillary structure of the wood and thus prevent dimension changes even when water is absorbed or given off. When the moisture in green wood is replaced by a liquid completely miscible with water, and that liquid, in turn, is replaced by a suitable resin or wax, a large part of the normal seasoning shrinkage is avoided, and the subsequent dimension changes with variations in moisture content are much less than in untreated wood. It has also been found (18) that by treating dry wood with a solution of materials that subsequently react and produce synthetic resins in the fine capillary structure, the normal shrinking and swelling of the wood can be reduced by as much as 50 to 70 per cent. Both of these methods are too expensive to be generally applied, but they offer promise of being very useful for the treatment of valuable small articles, in which the attainment of a reduction in dimensional changes is of sufficient importance to justify an appreciable expenditure.

MOISTURE-RETARDING COATINGS

It has been generally observed by investigators that suitable films placed over the surface of wood are more effective in reducing moisture changes than impregnation treatments, although no practical coating yet devised will entirely exclude moisture from wood in ordinary service. The value of such films apparently depends upon their ability to prevent contact between the wood substance and exterior water, in either liquid or gaseous form. Coatings of aluminum leaf or aluminum powder in paint or varnish are the most suitable ones yet found, some of them retaining their effectiveness throughout long periods of exposure to weather (7).

Linseed oil offers but little protection, even when a substantial coating is applied to the wood. Drying oils are made much more effective, however, by the addition of resins (to form varnishes) or of pigments (to form paints); within certain limits, the effectiveness is directly influenced by the amount of resin or pigment added. Asphalt and pitch paints are almost as effective as those containing aluminum powder and are also inexpensive and reasonably durable if well made. However, they are so dark in color that it is difficult, if not impossible, to apply light-colored paints over them satisfactorily (1).

All coatings deteriorate with age or exposure, but the different materials vary widely in the relative permanence of their effectiveness. Furthermore, under continuous exposure to a given humidity, the moisture content of coated wood will ultimately approach that of untreated material, the difference being in the time required for the moisture absorption to take place.

PROTECTION AGAINST MECHANICAL WEAR

No treatments that are primarily intended to increase the resistance of wood to wear are in extensive use today. The abrasion of wood floors is commonly prevented or reduced by the finish that is applied to them. So long as the coating is maintained in good condition and appearance, the wearing effect of traffic is borne by the finish rather than by the wood. The modern "floor-seal" type of finish, which soaks into the upper surface of the wood and then dries, may add somewhat to the surface hardness of the floor; but occasional waxing is required, even with these finishes, to keep the wood surface from showing wear. Although the homeowner is usually concerned only with the appearance of his floors and gives little or no thought to preventing wear, he actually does protect the wood by maintaining good appearance.

With heavy-duty floors, such as are used in warehouses and factories and on platforms, wear is far more important than appearance. When the abrasion is severe, deterioration may be retarded by the selection of resistant woods and by the method of laying the floor. Hard maple, birch, and black gum, for example, stand up better than most other woods under the punishment of heavy traffic; but when used out of doors or under other conditions that favor decay, they require preservative treatment to prevent their early failure. Floors made of softwood lumber resist wear better when the individual boards are laid "edge grain" to the traffic than when the "flat-grain" surfaces are exposed. With flat-grained flooring, however, surface splintering and wear will be less when the strips are laid with the convex side of the annual rings (bark side) up than when they are placed in the reverse position. "End-grain" surfaces are far more resistant to wear than the sides of the wood, and this fact is taken advantage of in the use of wood blocks for flooring and pavements of various kinds. The preservative treatment usually given to these blocks may contribute somewhat to their wear-resisting properties, but the chief effect of the impregnated chemicals is to prevent decay and the resultant softening of the wood.

The hardness of wood can be increased by impregnation with suitable materials, but none of the methods developed up to the present time has been put to extensive use. This is probably due in large measure to the cost of such treatments and, in some cases, to their undesirable effects on other wood properties. For most uses, it is undoubtedly simpler and less expensive to select a wood of suitable natural hardness than to impregnate a soft wood with some hardening material.

Kobbé reports (8) that the hardness of wood can be considerably increased by impregnation with sulphur, and recommends the use of sulphur-treated material for paving blocks and other heavy traffic purposes. However, such a treatment not only adds considerably to the weight of the wood but also increases its inflammability and makes it corrosive to iron. Synthetic resins, such as Bakelite, undoubtedly increase the hardness of wood but are too expensive for ordinary purposes. Resin treatment may be very practical, however, for small articles such as handles and golf-club heads, which are easily impregnated and can absorb the increase in cost.

A claim that is very often made in patents for preservatives, or in literature promoting them, is that the chemicals involved harden the wood. As a general rule, this has no basis in fact and can be ignored, unless the process actually provides for the injection of a considerable quantity of a hard material into the wood.

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CHAPTER XII

FIRE-RETARDING TREATMENTS

Fire exacts a toll of close to 10,000 lives a year in the United States as well as destroying an average of nearly half a billion dollars' worth of property annually. As indicated by the records of the National Board of Fire Underwriters, approximately half of the monetary loss may be attributed to frame buildings and other structures containing considerable quantities of wood, a circumstance that, at first glance, might seem to suggest the desirability of eliminating wood as a general construction material. However, the proportion of fires in wooden buildings is not excessive when it is considered that such structures greatly outnumber the other types, especially in rural districts, where they may constitute 98 per cent of all forms of construction. Furthermore, it has been repeatedly demonstrated that the greatest fire hazard in any class of building is usually to be found in the furnishings and other contents. So long as houses and other structures contain abundant quantities of easily ignited fabrics, upholstery, and general furnishings, or are used to store inflammable products, serious fire losses are bound to occur. In such cases, it may make little difference whether the structures are made of wood or of noncombustible materials. It is well recognized that care in preventing the inception of fires and the quick extinction of those that do start are far more important factors in the general problem of fire prevention than the type of construction involved. Despite these facts, however, it is apparent that the development of practical methods of reducing the extent to which wood may act as a contributory agent in the burning of a building may play an important role in saving lives and property.

While many of the construction materials in use today will not take fire, none of them is "fireproof," in the sense that it is not subject to injury when exposed to excessive heat. Iron and steel structural members are quickly and easily twisted and crushed under load when exposed directly to fire temperatures.

For this reason, safety provisions may require that the metal supporting members of a building be encased with concrete, brickwork, or other noncombustible insulating material. Concrete, brick, tile, and stone are likely to crack, chip, and spall off when subjected to high temperatures, especially if they are subsequently cooled suddenly, as by water from a fire hose.

Although wood is a combustible material, it is consumed so slowly in large sizes that heavy timbers may retain considerable strength even after long periods of continued fire exposure. This fact is recognized in the so-called *slow-burning heavy-timber construction*, originally known as *mill construction*, used in many industrial buildings. When ignited, the large wood beams and columns in structures of this type soon develop a charred shell which retards combustion to a marked degree. Actual tests have shown that these heavy timbers possess greater fire resistance than unprotected structural-steel supports (3, 11). Furthermore, it is possible to protect wooden columns and beams to some extent by covering them with gypsum wall board, metal, or other material that will prevent the direct exposure of the wood to flames.

When wood is exposed to high temperatures, it begins to decompose, giving off inflammable gases which ignite and tend to increase further the temperature of the wood, thus accelerating its decomposition. According to Truax (17):

> Research in the fields of wood distillation and combustion indicates that the decomposition of wood subjected to increasing temperatures consists of the following steps: Vaporization of the moisture in the wood (up to 212°F.); volatilization of extraneous materials (200° to 300°F. or higher); scorching and the slow evolution of inflammable gases (300° to 400°F.); charring with more rapid evolution of inflammable gases, accompanied by glowing and eventual flaming (400° to 700°F.); and quick ignition of inflammable gases and glowing of charcoal (700° to 950°F.).

Thus, wood may undergo combustion at temperatures far below the estimated 1700°F. or more attained in actively burning buildings.

The danger of rapid destruction of wooden buildings by fire can be minimized (*a*) by design and construction details which may cause a blaze to smother itself or will at least retard the spread of the flames and thus afford time for getting extinguishing apparatus into action, (*b*) by the installation of automatic sprinklers, or (*c*) by treating the wood in such a way as to make it highly resistant to burning. The following discussion is concerned only with the last-mentioned procedure, and is devoted chiefly to the impregnation of wood with fire-resistant chemicals, although some attention is given to the use of suitable surface coatings.

Wood that is impregnated with fire-retardant chemicals is commonly referred to as "fireproofed," and the methods of treatment as "fireproofing." Such terms are technically incorrect, for even though the treated wood may not spread flame or contribute to its own combustion, it will still char and ultimately decompose if continuously exposed to high temperatures. However, no more preferable terminology has been coined, and these popular descriptive designations have been retained in this text, despite their recognized scientific inexactness.

Attempts to reduce the inflammability of wood and other organic materials were made in very ancient times. Hartman (6), in a brief historical summary of the early fireproofing endeavors, reports that the Romans used vinegar as a fire retardant as early as the fourth century B.C. and later employed solutions of alum for the same purpose. A British patent, issued in 1625, covered a method for fireproofing the wood, canvas, and ropes of ships. Since that time, recommendations have been made, patents granted, and discussions published in increasing volume, and literally hundreds of formulas and processes have been proposed, although only a few of them have had sufficient merit to warrant actual commercial application. However, even the most successful processes have had only very limited use, chiefly because of the expense involved, and there is still urgent need for further research on the problem of devising economical methods for making wood resistant to burning. If the cost of effective treatments can be sufficiently reduced, fireproofing will be much more generally applied to wood than at present, and, to the extent that this is done, buildings and other structures will be made safer.

THE FIREPROOFING INDUSTRY IN THE UNITED STATES

The chemical impregnation of wood to render it fire resistant was first undertaken on a commercial scale in this country in 1895, in response to the demand created by the U.S. Navy Department specifications, which required the use of fireproofed wood in the construction of decks and certain other parts of all new warships (5). Further impetus was given to the development of the industry by the 1899 revision of the New York City Building Code, which provided for the use of chemically treated wood for floors, inside window frames and sash, doors, trim, and other interior finish in fireproof buildings over 12 stories high. The general features of this provision have been retained in the subsequent revisions and amendments of the code.

The Navy Department early experienced trouble with the fireproofed material, due to the action of the impregnated chemicals under the damp conditions to which the wood was subjected on vessels. The injected chemicals had a corrosive effect on metal fastenings, made the wood so hygroscopic that paint and varnish coatings gave unsatisfactory service, and afforded only temporary protection to wood exposed to the weather. These objections, coupled with the high cost of the treated wood, led the Navy Department to discontinue its use in 1902. When installed under dry conditions, however, the material gave much more satisfactory results, and its use for interior woodwork in land structures was continued despite the action of the Navy Department.

The commercial fireproofing process originally employed in the United States is reported to have been developed by Max Bachert, to whom was assigned U. S. patent 502,867, covering the use of ammonium phosphate and ammonium sulphate and granted to Lina Schüler on Aug. 8, 1893. Bachert's process was subsequently patented in England (Brit. pat. 2,821, May 24, 1895) and is said (6) to have initiated the fireproofing industry in that country in 1897. The early success of the Electric Fireproofing Company, organized to operate the Bachert process in the United States, and the stimulation of building activity in New York City between 1900 and 1903 led to the formation of a number of additional treating concerns, most of which were short-lived. The curtailment of market expansion undoubtedly resulted in competition which some of the companies were unable to meet, but careless and improper treatments probably played an important part in eliminating most of them. The real nemesis of the inferior processes was probably the testing procedure adopted by the New York Building Department in 1903, as a means of determining if impregnated wood actually had the required resistance to fire. The few companies that managed to survive the early years of the industry continued to supply the demand for fireproofed wood until 1917, when production was discontinued as the result of government curtailment of all nonessential building operations.

At the close of the World War, the government restrictions were removed, and a limited market for treated wood was again created in New York City. The industry has made some progress since 1919 but is still in the formative stage. A considerable number of new processes have been developed, but these have not been generally successful. The Bachert process was revived in 1926, being taken over by the Protexol Corporation of Kenilworth, N.J., which has assumed leadership in the fireproofing industry.

Fireproofed wood has not been extensively used in the United States, and the annual production has never exceeded a few million feet. Since 1902, the market for the product has been largely confined to New York, and even in that city the material has rarely been employed except where required by law. While this condition has prevailed chiefly because of the relatively high cost of the treated wood, the demand has also been limited by the unsuitability of the material for permanent exterior use and the lack of a definite endorsement by fire underwriters. The last-mentioned obstacle was partially removed in 1935, with the issuance of a report on fire-resistance tests, made by the Underwriters' Laboratories of Chicago on red oak and maple lumber impregnated by the Protexol Corporation (2). This report stated: "These products will not ignite readily, contribute fuel, nor add to spread of fire; they will char progressively when exposed to fire, but will cease glowing shortly after the exposure." The approval of this lumber has done a great deal to create confidence in fireproofed wood and may prove to be the foundation for a substantial increase in its use.

COMPARISON OF FIRE-RETARDING CHEMICALS

A great deal of investigative work has been done in attempting to ascertain the comparative fire-retarding effectiveness of a wide variety of chemicals when injected into wood. The U. S. Forest Products Laboratory has made extensive studies in this field and published numerous reports (8, 9, 10, 14, 17, 19, 20), and the results of investigations in a number of other countries have also been made available in recent years (4, 12, 15, 16). Plunguian and Jahn, at the University of Idaho, have tested the efficacy of chemicals in fiber boards (13).

These various researches have usually had one or more of the following objectives: (*a*) to devise tests that would satisfactorily measure the fire resistance of treated and untreated wood; (*b*) to make a survey of the effectiveness of various chemicals; (*c*) to learn the manner in which chemicals reduce inflammability; and (*d*), most important of all, to originate inexpensive, effective, and otherwise satisfactory fire-retarding formulas. In a few cases, however, the principal aim has been to set up formal approval tests (2) or to establish classifications for different degrees of fire resistance for building-code or insurance-rate purposes (16).

METHODS OF TESTING FIRE RESISTANCE

It is obviously necessary to have well-defined methods for measuring fire resistance, if reliable comparisons are to be made of the effectiveness of different chemicals or treating processes. Unfortunately, no one form of procedure has been generally adopted, and practically every investigator has felt called upon to devise a new and different test. This situation is due mainly to the fact that none of the methods measures the property of fire resistance in basic units. All of them are empirical in character, and the results obtained vary according to the size and shape of the wood specimens used and the exact details of the test procedure, both of which are purely arbitrary. Consequently, the data secured by different investigators may be in no wise comparable; in fact, unless great care is taken, somewhat the same objection may characterize the results derived by any one investigator at different times.

The test methods are usually based upon the fact that, when untreated wood is ignited under ordinary conditions, there is a marked tendency for the flame to spread and for the temperature to increase, thus accelerating the rate of destruction. Wood that is adequately impregnated with suitable chemicals will also char, and even flame to some extent, so long as it is exposed to fire temperatures. Under the conditions of the tests thus far devised, however, the flame will not spread beyond the area of direct exposure, and the treated wood does not build up the temperature or contribute to its own decomposition. Furthermore, as soon as the source of heat is removed, the burning will promptly cease.

The U. S. Forest Products Laboratory *fire-tube test* (18) is more widely used than any other single method of measuring resistance to *flame spread* (Fig. 103). In this, the test specimen, which is $\frac{3}{8}$ by $\frac{3}{4}$ in. in cross section and 40 in. long, is hung in a perforated sheet-metal tube at the end of a balance arm, and a standardized gas flame is applied to the lower end of the wood sample for 4 min. When an untreated specimen is kindled in this way, the flame quickly spreads to the upper end of the piece, and the temperature at the top of the tube will remain high until the sample is largely consumed or reduced to charcoal. In contrast, a thoroughly

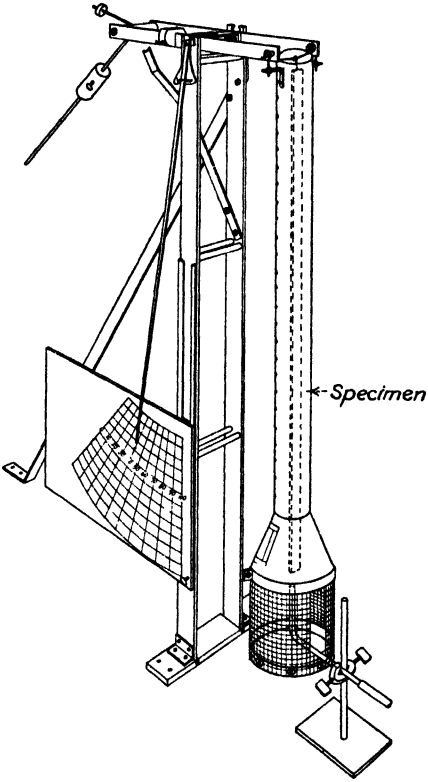

Fig. 103.—U. S. Forest Products Laboratory fire tube. The loss in weight, as the specimen burns in the tube, is indicated directly in percentage by the pointer on the scale. (*U. S. Forest Products Laboratory.*)

treated specimen will cease burning almost as soon as the gas flame is taken away, and the temperature will remain relatively low. During the test, the loss in weight of the specimen is indicated by a pointer on a scale, which reads in percentage of the original weight. Experience has indicated that untreated wood samples generally lose from 80 to 90 per cent of their weight and build up temperatures of 700 to 800°C. at the top of the tube, while well-treated specimens lose only 15 to 20 per cent of their weight and seldom raise the temperatures at the top of the tube

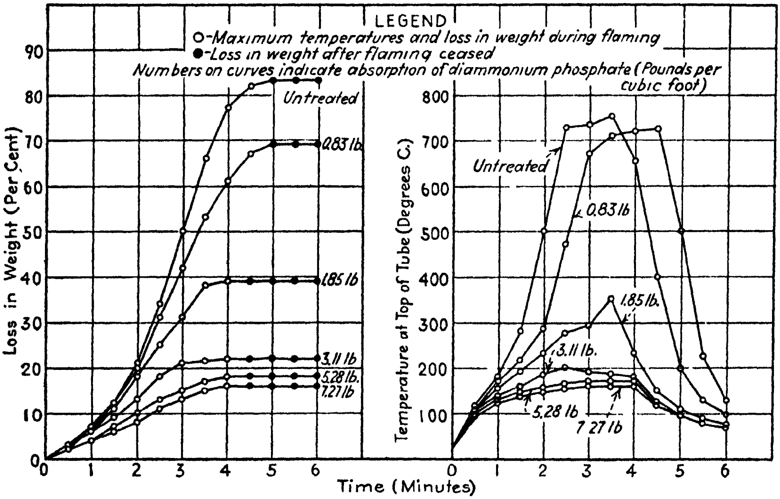

FIG. 104.—Typical curves of weight loss, and temperature at top of tube, for treated and untreated wood in fire-tube test. (*U. S. Forest Products Laboratory.*)

above 200°C. Figure 104 shows typical weight-loss and temperature curves for treated and untreated wood.

The effectiveness of a given treatment should not be judged by flame spread alone, for some of the chemicals that are satisfactory in controlling this feature of burning offer little or no resistance to the *penetration of flame* through the wood. The National Bureau of Standards determines flame penetration by placing a test board on a ring stand over a Bunsen burner and noting the temperature changes on the upper surface of the board and the time required for the flame to show through. The Forest Products Laboratory places a test board against an opening in the side of a small furnace; gradually increases the temperature in accordance with the standard time-temperature curve (Fig. 105); and notes the changes in temperature on the outer surface of the board, the time required for the flame to show through, and the loss in weight of wood per minute.

Three different tests—shavings, crib, and timber—are used by the city of New York for the inspection of fireproofed wood offered for use under the provisions of the building code (5, 7). In the *shavings test,* a mass of shavings is cut from a sample of treated wood and placed in a metal basket. The mass is then ignited by a Bunsen burner, and the height of the flame and the time required to consume the shavings are noted. It is practically impossible to standardize the details of this test so as to obtain comparable results with different woods and treatments.

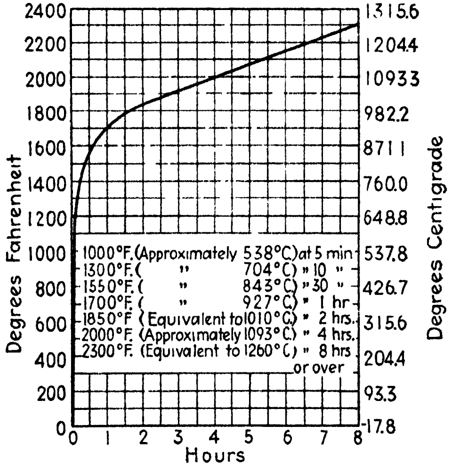

Fig. 105.—Standard time-temperature curve for regulating furnace temperatures during fire tests. This curve has been adopted as standard by the National Fire Protection Association, the American Society for Testing Materials, and other organizations concerned with fire testing.

The *crib test* is made upon 20 samples of treated wood, each ½ in. square and 6 in. long, which are cross piled upon a ring support in five equal tiers, making a pile 6 in. square and 2½ in. high. The crib is placed 6 in. above a Bunsen burner, the flame of which is directed on the wood for 1 min. Specification requirements for treated wood are that the flame must not persist more than 20 sec. after removal of the Bunsen burner or the glow last more than 30 sec. This is essentially a flame-spread test and, when carefully standardized, gives very useful results.

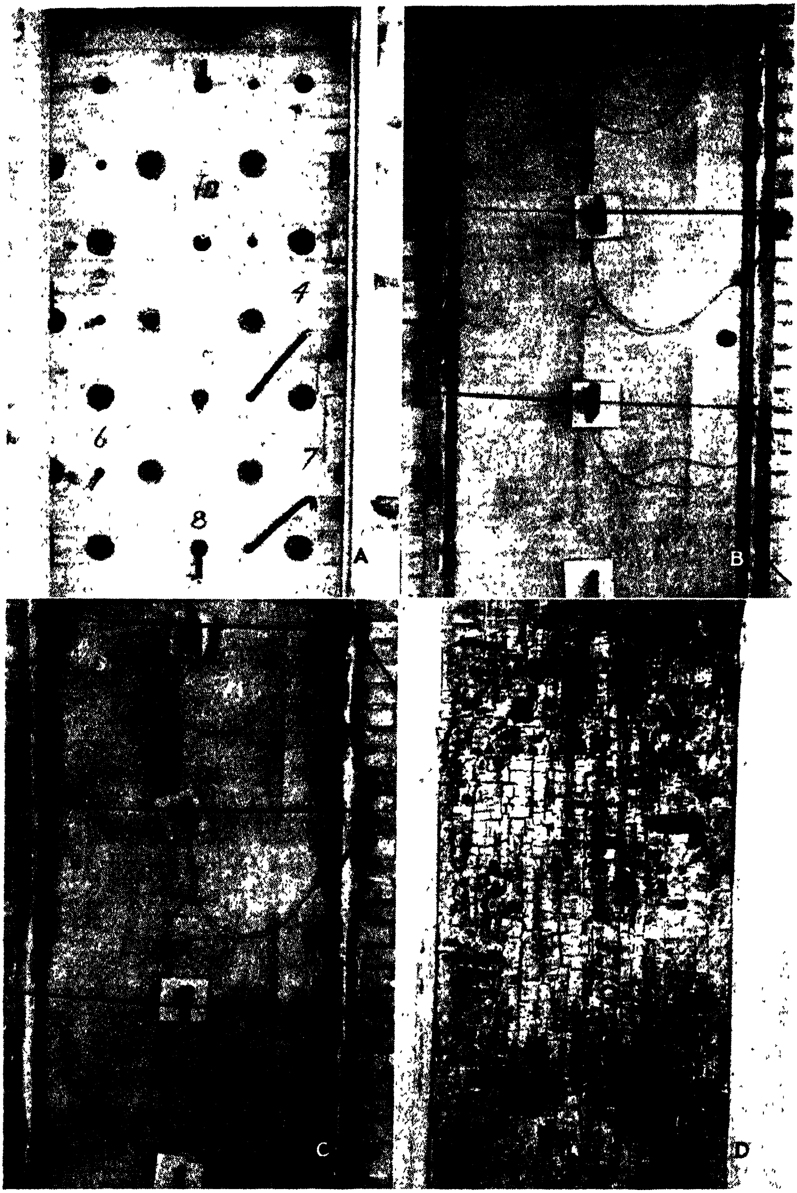

FIG. 106.—Fire testing of full-sized doors *A*, interior of door-testing furnace, viewed through the door frame, showing gas inlets (large circles) and thermocouple tubes; *B*, a door at beginning of test—thermocouples (under asbestos pads) indicate temperature on outside face of door; *C*, outside face of same door, at end of 1-hr. test; *D*, inside face, after 1-hr. test. (*U. S. Forest Products*

The *timber test* is made upon two samples, each ¾ by 1½ by 12 in. in size, which are laid edge to edge across the opening in the top of a crucible furnace and exposed for 2 min. to flame at a temperature of 1700°F. The samples are then removed from the furnace, and the duration of flame and glow is noted. The pieces are then cut through at the most burned section, and the area of unburned wood is measured. It is specified that the flame must not persist longer than 15 sec. nor the glow longer than 20 sec.; the unburned area must not be less than 55 per cent of the original cross section of hardwoods or 45 per cent of softwoods. This is primarily a flame-penetration test and gives good results when conducted under properly controlled conditions.

The various small-scale tests are very useful for laboratory surveys, inspection purposes, and general comparisons of fireproofed woods; but before any chemicals or methods of treatment can be fully evaluated or approved, suitable tests must be made on actual assemblies, such as doors (Fig. 106) or sections of floors or walls. In investigations of this latter type, the fabricated structural units are commonly placed against the opening of a large furnace and heated in accordance with the time-temperature curve, to ascertain the time required for flame to penetrate the wood. Flame-spread tests have also been made on a large scale (2). In some cases, a definite load is placed upon a test panel, in order to determine the time elapsing before failure. All of these methods are necessarily expensive and time consuming, however, and most investigators have preferred to work with the small-scale tests.

EFFECTIVENESS OF VARIOUS CHEMICALS

The general effectiveness of any fireproofing treatment depends upon both the kind of chemical used and the amount injected into the wood. Surface applications or very low absorptions of even the most efficient substances will not afford much protection. The results of fire-tube tests, made by the U. S. Forest Products Laboratory on specimens of yellow birch and southern pine treated with different amounts of diammonium phosphate (17), are shown in Fig. 107. These findings indicate that, with the particular chemical and species concerned, an absorption of at least 8 lb. of dry salt is required per 100 lb. of air-dry wood if high fire resistance is to be obtained. This is the equivalent of about 3 to

3½ lb. of chemical per cubic foot of wood. In view of the fact that the absorption should bear some relation to the dimensions of the pieces to be impregnated (page 250), however, a somewhat lighter treatment may be sufficiently effective for commercial sizes of lumber.

Data obtained by the U. S. Forest Products Laboratory (20), from fire-tube tests made on specimens cut from nominal 1-in. boards treated with different absorptions of various chemicals and chemical mixtures, are given in Table XXIII. In practically every case, an absorption of more than 5 lb. per cubic foot was needed to keep the loss in weight of wood below 20 per cent. The absorptions required for a high degree of protection in large-scale tests on assembled structural units have not been determined up to the present writing.

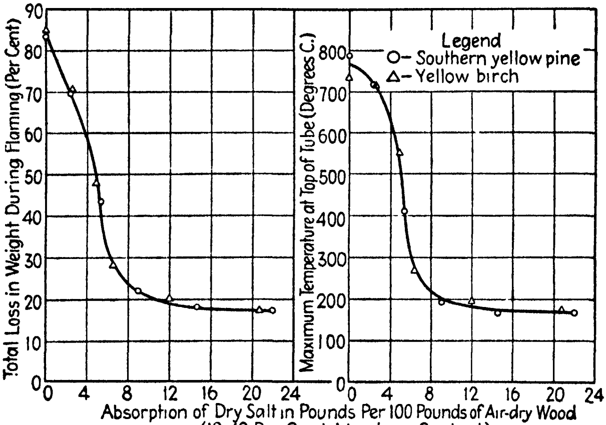

Fig. 107.—Fire-retarding effectiveness of different absorptions of diammonium phosphate in southern pine and yellow birch, as indicated by the fire-tube test. Each plotted point represents the average results of 16 to 20 tests. (*U. S. Forest Products Laboratory.*)

The chemicals listed in Table XXIII, while constituting only a small fraction of the total number tested to date, are, for the most part, those that have seemed most promising. The indicated superiority of the dibasic and monobasic ammonium phosphates is generally recognized by investigators, and one or the other of these salts is probably included in most of the fire-retarding formulas now in commercial use. Phosphoric acid is also outstanding in its ability to prevent both flaming and glowing of

TABLE XXIII.—RESULTS OF U. S. FOREST PRODUCTS LABORATORY FIRE-TUBE TESTS ON WOOD TREATED WITH DIFFERENT ABSORPTIONS OF VARIOUS CHEMICALS (20)

Chemical	Percentage of total anhydrous chemical used	Absorption of anhydrous chemical per cubic foot of wood, pounds	Loss in weight,* per cent	Tendency to glow†
None (untreated wood)	.		83.5	Moderate
Ammonium chloride	100	1.50	66.5	Slight
		2.10	53.8	Slight
		3.14	23.2	Slight
		5.36	24.2	Slight
		7.54	19.7	Very slight
Ammonium phosphate (dibasic)	100	0.90	69.4	None
		1.84	43.4	None
		3.23	21.8	None
		5.15	17.9	None
		7.25	17.1	None
Ammonium phosphate (monobasic)	100	0.91	67.4	None
		1.84	56.9	None
		2.60	26.5	None
		4.99	19.0	None
		7.29	15.7	None
Ammonium sulphate	100	1.35	70.4	Slight
		1.86	64.3	Slight
		3.17	31.6	Slight
		4.96	25.9	Slight
		6.70	20.1	Slight
Sodium tetraborate (borax)	100	1.02	54.4	Moderate
		1.76	36.0	Moderate
		3.08	25.0	Moderate
		5.36	21.8	Moderate
		6.02	20.0	Moderate
Boric acid Sodium tetraborate (borax)	60 40	1.18	69.5	Slight
		2.08	64.6	Slight
		3.11	60.3	Slight
		5.32	28.3	Slight
		7.14	19.1	None
Borax Ammonium phosphate (monobasic)	67 33	1.09	68.6	Very slight
		2.20	52.9	Very slight
		3.41	27.2	None
		5.69	16.5	None
		8.49	14.6	None
Boric acid	100	1.00	78.2	None
		2.04	75.1	None
		3.32	72.2	None
		5.42	66.8	None
		6.83	58.4	None
		8.74	29.9	None
Magnesium chloride Ammonium phosphate (monobasic)	45 55	1.09	77.1	None
		2.19	72.0	None
		3.19	67.8	None
		5.85	21.1	None
		8.39	17.4	None
Magnesium chloride Ammonium phosphate (monobasic) Ammonia gas	39 47 14	1.24	71.4	Very slight
		2.61	52.5	None
		3.88	22.5	None
		6.63	16.6	None
		9.66	15.6	None

TABLE XXIII.—RESULTS OF U. S. FOREST PRODUCTS LABORATORY FIRE-TUBE TESTS ON WOOD TREATED WITH DIFFERENT ABSORPTIONS OF VARIOUS CHEMICALS (20)—(*Continued*)

Chemical	Percentage of total anhydrous chemical used	Absorption of anhydrous chemical per cubic foot of wood, pounds	Loss in weight,* per cent	Tendency to glow†
		1.14	76.9	Moderate
Magnesium chloride	44	2.34	73.3	Moderate
Sodium phosphate	56	3.57	70.2	Slight
(monobasic)		5.78	54.2	Very slight
		8.83	33.2	Very slight
		1.32	66.4	Slight
Magnesium chloride	38	2.64	54.9	None
Sodium phosphate	48	4.01	27.4	None
(monobasic)		6.85	19.4	None
Ammonia gas	14	10.09	16.2	None
		1.06	75.7	None
		2.18	70.0	None
Magnesium phosphate	100	3.10	67.4	None
(monobasic)		5.45	54.5	None
		7.44	18.4	None
		1.31	70.0	None
Magnesium phosphate	81	2.68	49.8	None
(monobasic)		3.85	21.6	None
Ammonia gas	19	6.66	16.1	None
		9.38	14.0	None
		1.13	73.8	Moderate
		1.88	63.5	Moderate
Zinc chloride	100	2.77	47.7	Moderate
		5.08	20.7	Moderate
		8.28	18.3	Moderate
		1.04	75.8	None
Zinc chloride	54	2.09	69.8	None
Ammonium phosphate	46	3.24	65.8	None
(monobasic)		5.40	22.9	None
		7.60	18.4	None
		1.19	72.6	None
Zinc chloride	48	2.27	67.9	None
Ammonium phosphate	40	3.74	37.8	None
(monobasic)		6.15	18.1	None
Ammonia gas	12	8.55	16.3	None

* When flaming stopped.

† Based on untreated wood as "moderate."

wood, and similar properties are possessed by aluminum sulphate, ammonium bromide, ammonium chloride, and monobasic zinc phosphate. It should be noted, however, that not all of these chemicals can be safely used without the addition of other materials, for some of them are corrosive or have other disadvantages that must be given consideration.

In contrast to these substances, many other chemicals have an undesirable effect on the glowing of wood, when used in sufficient quantity to inhibit flaming of the material. Such salts as ammonium oxalate, calcium chromate, chromic acid, chromic chloride, cobaltous chloride, cupric chloride, manganese chloride, and sodium molybdate increase the tendency of wood to glow after flaming ceases (10). Iron salts have also been found to have the same property. Some chemicals are so outstanding in this respect that, when a glowing piece of treated wood is removed from contact with the heat source, it will continue to glow for hours, until entirely consumed.

SOURCE OF EFFECTIVENESS

Although numerous attempts have been made to determine just how chemicals act in making wood resistant to burning, the results obtained to date have not been conclusive. Three possible high-temperature reactions have been suggested as contributing to the effectiveness of the successful fire-retardants, *viz.*, (*a*) liberation of water of crystallization, (*b*) evolution of noncombustible gases, and (*c*) the property of fusing to a viscous mass.

When wood impregnated with chemicals having a high percentage of water of crystallization is exposed to high temperatures, the water is given off in the form of vapor and tends to dilute the combustible gases formed by the decomposition of the wood. Investigation has indicated, however, that any such action is a contributory rather than a primary cause of fire resistance, for no consistent relationship was found when the effectiveness of various chemicals was plotted against their water of crystallization (10). In fact, a number of the most efficient chemicals, including the ammonium phosphates, are entirely devoid of water of crystallization, while some of the least efficacious substances contain a great deal of it.

Some of the investigated chemicals decompose when heated, giving off nonflammable gases which may dilute the evolved wood gases sufficiently to interfere with their combustion. This characteristic does not seem to be of outstanding importance in reducing the susceptibility of wood to burning, however, although it probably contributes to the fire-retarding effect of the chemicals.

The chemical action that appears to be most important in controlling combustion is that of melting at fire temperatures to form a viscous liquid, which tends to coat the wood surfaces and thus cut off the supply of oxygen necessary for continued burning. The ammonium phosphates, borax, and boric acid possess this property to a high degree. However, there are many other more or less effective chemicals, including ammonium sulphate, ammonium chloride, aluminum sulphate, ammonium bromide, and monomagnesium phosphate, which do not fuse at high temperatures. It is evident that there is still a great deal to be learned about the manner in which various chemicals exert their fire-retarding influences.‡

CHEMICAL COST

The relative cost of the acceptable chemicals, based on the amounts that must be injected into wood to give the required degree of fire resistance, is of major importance in determining the suitability of these substances for commercial fireproofing purposes. The cost per pound of the ammonium phosphates is relatively high, and some of the less effective chemicals may give cheaper treatments, even though heavier absorptions are required.

TABLE XXIV.—WHOLESALE PRICES FOR FIRE-RETARDING CHEMICALS
(1937 trade-journal quotations)

Chemical	Quality	Approximate price per pound
Ammonia (gas)	Pure	\$0.16 to 0.22*
Ammonium chloride	Commercial	0.05 to 0.06
Ammonium phosphate, monobasic	Commercial	0.09 to 0.10
Ammonium phosphate, dibasic	Commercial	0 09 to 0.10
Ammonium sulphate	Commercial	0.01 to 0.02
Borax†	Commercial, 99½ per cent	0.02 to 0.03
Boric acid	Commercial, 99½ per cent	0.05 to 0.06
Magnesium chloride†	Commercial	0.02 to 0.03
Phosphoric acid	Commercial, 50 per cent	0.06
Sodium phosphate, monobasic	Commercial, anhydrous	0.08 to 0.09
Zinc chloride	Commercial	0.04 to 0.05

* In cylinders delivered in New York.
† Contains water of crystallisation.

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‡ Since the preparation of the foregoing discussion, Richardson has presented data (*Jour. Soc. Chem. Ind.*, **56**: 202T–205T, June, 1937) which indicate that efficient fire retardants have a chemical effect upon the wood, favoring carbonization at lower temperatures and decreasing the amount of carbon lost in volatile combustible form.

The merits of these ammonium salts are such, however, that most of the successful present-day processes use them in mixture with less expensive chemicals. Experiments have indicated that a small percentage of ammonium phosphate is sufficient to prevent glowing, while flaming can be eliminated if the bulk of the formula consists of a cheaper chemical, such as ammonium sulphate. The efficiency of this combination of ammonium salts was apparently recognized by Bachert (page 400).

The wholesale prices indicated in Table XXIV were quoted in 1937 for some of the more important chemicals listed in the preceding table. Some salts contain a high percentage of water of crystallization, and, in order to obtain equable comparisons with other chemicals, the cost per pound of these substances should be computed on the anhydrous basis. The absorptions indicated in Table XXIII do not include water of crystallization.

MISCELLANEOUS PROPERTIES

In addition to being effective and reasonable in cost, fire-retardant chemicals should be of such a nature that they do not impart any markedly objectionable characteristics to the treated wood. While it is recognized that the injection of large amounts of salts tends to make wood somewhat brittle, and that concentrated solutions of certain chemicals may actually disintegrate the material, there is no specific evidence that the substances used in the commercial fireproofing processes seriously impair the strength of wood. Any injurious effects that may be noted are more apt to result from the use of high treating temperatures and pressures than from the mere presence of the chemicals in the wood.

Chemicals that are definitely corrosive to metals not only cause serious damage to treating equipment but may even have an injurious effect on metal fastenings and fittings placed in contact with treated wood in service. The commercial ammonium phosphates, used alone or in mixture with ammonium sulphate, have been found to cause fairly rapid deterioration of the treating apparatus. However, it is possible partially to overcome this disadvantage by adding certain other chemicals to these salts.

Salts that are hygroscopic tend to absorb moisture vapor from the air and during periods of damp weather may cause significant amounts of water to accumulate on the surface of the treated wood. Such a condition encourages the corrosion of nails, screws, and hardware and shortens the service life of paint and varnish coatings. Although chemicals of this character may be highly fire retardant, they are entirely unsuited for fireproofing wood.

Many chemicals have an adverse effect on the gluing properties of wood. The extent to which any of these substances make it difficult to get good glue joints is an important consideration in determining their suitability for treating lumber or veneers that are to be used in the manufacture of such products as doors, furniture, and fixtures.

Wood that contains any large quantity of fire-retardant salts is definitely more difficult to saw and plane than untreated material, since the chemicals cause cutting edges to wear rapidly and necessitate frequent sharpening of tools. The amount of chemical present has a direct bearing on the working quality of the wood, and the nature of the substance may also have some effect. While this disadvantage cannot be avoided, it may be minimized by using tools especially designed for the purpose and, perhaps, by the proper selection of chemicals.

Various arsenates and arsenites are highly effective in retarding fire but cannot be recommended, because wood containing them gives off dangerous fumes when subjected to high temperatures. Chemicals of this character, if present in substantial quantities, would add to the hazards to which firemen and other occupants of burning buildings are exposed.

DECAY RESISTANCE

It is quite feasible to make wood resistant to both decay and fire, by including in the fire-retarding formula salts that are toxic to wood-destroying fungi. This is being done on a commercial scale at the present time, notably in the treatment of wood for use in mine shafts. Of the chemicals listed in Tables XXIII and XXIV, borax, boric acid, and zinc chloride are effective preservatives, and there are numerous other salts that could be used as toxicants.

RESISTANCE TO LEACHING

All of the chemicals generally recommended for fire-retarding purposes are soluble in water and will gradually leach out of treated wood when it is placed in contact with wet soil or exposed to the weather. Numerous attempts have been made to concoct treating solutions that will form insoluble compounds as the wood is dried after impregnation. Some progress has been made in this direction, although no such method has yet attained commercial success. The development of an economical, nonleachable, and effective treatment would greatly increase the field of usefulness of fire-retardant wood.

TREATMENT AND DRYING OF WOOD

The methods used in injecting fire-resisting chemicals into wood are substantially the same as those employed in treating the material with preservative salts, the chief difference being in the high net absorptions required with the fire retardants. The full-cell process is generally employed, because empty-cell methods necessitate the use of much stronger treating solutions and offer little advantage otherwise. Except for the fact that dry kilns must be provided, the required equipment is basically the same as that used at a regular wood-preserving plant (Fig. 108).

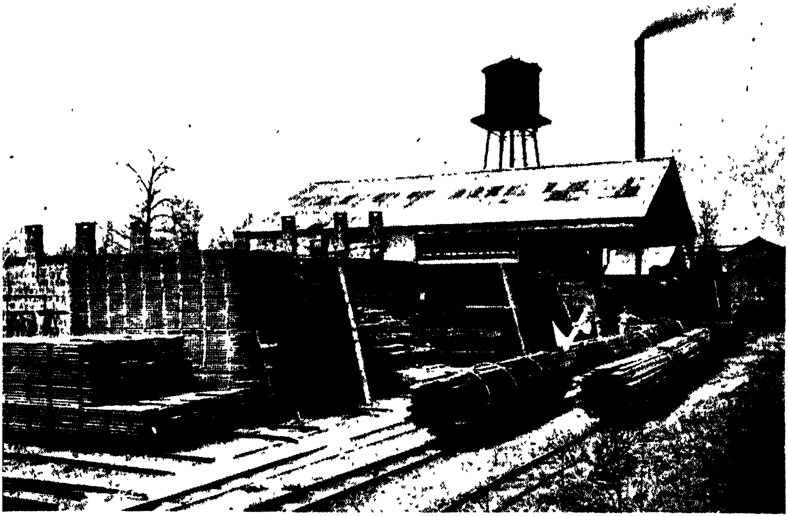

Fig. 108.—A commercial fireproofing plant. Treating cylinders shown at extreme right. Dry kilns partially obscured by lumber piles at left. (*Protexol Corp.*)

Since fireproofed wood is used mostly for interior trim and floors in buildings, the lumber is usually selected for its appearance rather than for the facility with which it can be treated. As a result, the plant operator is frequently required to impregnate woods that are highly resistant to penetration, such as the heartwood of white oak, red gum, or very refractory foreign species. In such cases, the problem is to find treating conditions that will give the necessary absorption and penetration and yet not seriously injure the wood. Charges of valuable lumber have occasionally been so badly collapsed, honeycombed, or checked by severe treatment as to be virtually useless.

Treatments that leave high concentrations of effective chemicals in the outer layers of wood afford considerable protection, even though the interior may not be impregnated. However, it is necessary to obtain practically complete penetration, if the material is to be required to pass the fire-tube, crib, timber, or certain other acceptance tests. Thorough penetration may also be essential in lumber that is subsequently to be cut up or remanufactured, since such operations may otherwise expose untreated or very poorly treated wood. To avoid any such impairment of the effectiveness of the treatment, it is particularly desirable that lumber of refractory species be fashioned as nearly as possible to its finished form and dimensions before being impregnated. Most fireproofed lumber must be planed or sanded after treatment, to remove the rough discolored surface and prepare the wood to receive a finish. These surfacing operations should be as light as practicable, since they reduce the thickness of the most heavily treated layer of wood.

The extent to which wood should be dried after treatment and the method of seasoning to be employed depend primarily upon the use to which the material is to be put. Most of the fire-retardant lumber is used for trim, flooring, and other forms of interior woodwork in heated buildings, and, consequently, it is necessary to reduce its moisture content to approximately 6 or 7 per cent, in order to avoid shrinkage difficulties after installation. Since this degree of dryness can be attained only by artificial seasoning methods, efficient dry kilns are essential equipment for fireproofing plants. The operation of these kilns requires considerable care, since the temperatures and humidities must be so adjusted that the wood is not seriously weakened and the chemicals are not drawn toward the surface. Material to be used for scaffolding, form lumber, and other general construction purposes does not need to be dried to so low a moisture content as finished woodwork and can be made ready for service by air seasoning. For certain inexacting uses it may be necessary to dry the wood only long enough to bring the shipping weight down to a reasonable point; but in most cases, relatively long seasoning periods are indicated. If the moisture content of the lumber must be reduced to 12 to 15 per cent, it may be preferable to kiln dry the wood, in order to shorten the time before delivery can be made.

At the present time, several different classes of treatment are available, varying in fire resistance and cost, chiefly according to the amount of chemical retained in the wood. The most effective of these is the so-called *Class A* (or incombustible) treatment, designed for interior trim, flooring, and other milled products that are required to pass rigid acceptance tests. The present commercial charges for this type of treatment are about $80 per thousand board feet, exclusive of the cost of the lumber itself, and compare quite favorably with the 1927 cost range of $95 to $100. In itemizing the 1937 charges, the chemical cost is estimated at $25, the cost of impregnation at $10, and the expense of kiln drying at $18; the balance includes charges for royalties and overhead, the latter varying with the continuity of operations. The *Class C* (or slow-burning) treatment, selling for $38 to $40 per thousand board feet; and the *Class D* (or noninflammable) treatment, priced at $28 to $30, carry estimated chemical charges of $12 and $7.50, respectively. Kiln drying is not provided for in either case, but an added charge of $1 per thousand feet is made for sticking the lumber for air seasoning; impregnation costs are estimated to be approximately the same as for the Class A treatment. The Class D treatment is usually acceptable for scaffolding, which has a limited mechanical life, although in repairing the Washington Monument the engineering department of the National Park Service specified a Class C treatment and purchased approximately 60,000 ft. b.m. of Douglas fir lumber for use as platform planking (1). The charge for the *Class B* (or decay- and ignition-resistant) treatment may vary considerably, depending largely upon the amount and kind of preservative used; three carloads of mine-shaft lumber were treated early in 1937 at a cost of $29 per thousand feet, a figure that included $9 for chemicals, $10 for impregnation, and $1 for sticking for air drying.

FIRE-RETARDANT COATINGS

Although surface coatings were first used by the early Romans to protect wood from burning (6), they have never been extensively employed for that purpose, despite their low cost and the ease with which they can be applied. In recent times, many investigators have attempted to develop satisfactory treatments of this type, and numerous patents have been issued, but no coating has yet received general recognition as a practical means of making wood effectively and permanently resistant to fire.

Mud, plaster, Portland cement, and similar noncombustible materials will prevent burning, except under severe and prolonged exposure to fire, provided they are applied over the surface of the wood in sufficiently thick layers. As ordinarily understood, however, the term *fire-retardant coatings* does not pertain to treatments of this character but refers rather to coverings such as can be applied conveniently with a brush. Such coatings tend to insulate the wood from the heat, or prevent the free access of the oxygen required for combustion. If the exposure to heat is long continued, the protective layer will ultimately be broken down, but good coatings can afford considerable opposition to flame penetration and high resistance to flame spread.

One of the most effective fire-retardant coatings known is sodium silicate, or "water glass." A newly applied coating of this material has the property of intumescence, that is, it softens and swells at high temperature to form a bubbly mass which is much thicker and a much better insulator than the original layer. For this reason, fresh applications of sodium silicate are capable of preventing the spread of any ordinary small fire and can afford a high degree of protection at little cost. Unfortunately, as such coatings age, they tend to lose their property of intumescence and, with it, their effectiveness. Because of this gradual reduction in fire resistance, sodium silicate is to be recommended for use only where temporary protection is needed or where the covering can be renewed frequently. Phosphoric acid and ammonium phosphate also have the property of intumescence to a considerable degree, and coatings containing these chemicals may be highly effective.

There are numerous patented and trade-marked fire-resisting paints on the market, some of which are claimed to be suitable for outdoor use. No comprehensive study appears to have been made for the purpose of determining the relative effectiveness and permanence of these materials. Most of the nonproprietary paints and coatings are not weather resistant and, consequently, are suitable for indoor use only.

USES FOR FIRE-RETARDANT WOOD

The present uses for wood impregnated with fire-retarding chemicals are limited mainly to interior trim, doors, and flooring in so-called "fireproof buildings." In fact, it is the legal restriction on the use of untreated wood in such buildings in New York City that provides the principal demand for these fireproofed products. Occasional lots of milled woodwork are also treated for use in buildings where fire-retardant wood is not required by law, but where the builder especially desires it.

Occasionally, the wood scaffolding used in the construction of large buildings has taken fire, causing material damage to the structure and heavy financial loss to the contractor. Such destruction can be largely avoided through the use of fireproofed wood, and treated scaffolding has been specified on a number of recent jobs. Properly treated wood is accepted by the New York, Philadelphia, and Washington boards of fire underwriters at a reduced rate of insurance. The facility with which the impregnated chemicals may be leached from wood that is exposed to the weather may reduce the value of the treated lumber for exterior scaffolding, especially when it is reused repeatedly. The mechanical life of such material is usually rather limited, however, and it will probably be discarded before the effectiveness of the treatment is entirely lost. Furthermore, if the wood is properly painted, it should retain its fire resistance for a reasonably long period of time. Leaching is not a problem in scaffolding used for interior work, where the fire risk is usually greater.

Fireproofed wood has not been used to any extent in dwellings and other small buildings, mainly because the treated lumber costs appreciably more than untreated material, and the consumer has not been willing to assume the extra expense. If and when the cost of the treated wood is substantially reduced, the amount used will undoubtedly be greatly increased. Other suggested uses for fireproofed wood include form lumber, hod-hoist towers, and contractors' equipment; covered platforms and mill- and factory-roof planking; and, in the electrical field, distribution and fuse boxes, wire casings, and powerhouse construction.

As effective, weather-resistant coatings are developed, they will probably be used in the treatment of scaffolding, providing cheaper protection than the impregnation methods. There is also a distinct need for coatings that will maintain their efficacy indefinitely indoors, since such materials could be used to advantage within the walls of houses, on basement ceilings or rough partitions, and in other locations, where they would greatly reduce the danger of a fire gaining rapid headway from a small start.

Since fireproofing chemicals do not prevent charring, even thoroughly impregnated wood does not have any great advantage where there is continuous or frequent exposure to charring temperatures. The value of the treated wood lies in the resistance that it offers to flame spread, flame penetration, and glowing.

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APPENDIX

AN EARLY AMERICAN WOOD-PRESERVING PATENT

The following is a copy of one of the earliest, if not the first, American wood-preserving patents on record. It was granted to Dr. William Crook by the Province of South Carolina in 1716 and covers a preservative intended to protect ship planking from shipworms and decay.

No. 19

An Act for the Due Encouragement of Doctor William Crook of this Province in his Preparing and also Vending and Selling a certain Composition of his own Invention, One Part of which is the Oyle or Spirit of Tarr which with other Ingredients will Preserve the Bottom of Vessels from the River Worm and also the Plank from Rotting.

WHEREAS there is no person that ought to have and receive more encouragement than those who by their art and ingenuity have first invented, found out and discovered any secret which may redound afterwards to a public good and benefit, AND WHEREAS by the petition and humble request of the said William Crook exhibited to this General Assembly, setting forth that he has found out and discovered such a secret as aforesaid fitting to be encouraged for the benefit of navigation in general and for the more safety in shipping whereby trade and business may not only increase but likewise be rendered more beneficial to the merchants and particularly for the interest of this Province as experience in time may discover, BE IT ENACTED by his Excellency John Lord Carteret Palatine and the rest of the true and absolute Lords and Proprietors of this Province of South Carolina, by and with the advice and consent of the rest of the Members of the General Assembly now met at Charles Town for the South and West Part of this Province, and it is hereby ENACTED by the authority of the same, that the said William Crook for his encouragement and as a reward for so laudable an invention (Provided within three years time after the ratification of this Act demonstrates to the General Assembly of this Province that he can really and bonafide perform and fulfill such his invention) shall have free liberty to compound, make, vend, sell and dispose of his said composition, and that no other person or persons in this Province do presume to sell or otherwise dispose of any spirit or oyle of tarr or pretend to sell any composition whatsoever of the same nature or kind that comes from the vaporous part of tarr to any merchant or merchants or any other person or persons whatsoever in this Province of South Carolina without his the said William Crooks or his assigns leave and license for the space of seven years after the ratification of this Act, under the penalty and forfeiture of the sum of One Thousand Pounds Currant Money of this Province to the said William Crook, his Executors, Administrators or Assigns, which is to be sued for by Bill, Plaint or Information in any of the Courts of Record of this Province, wherein no Essoign, Protection, Wager of Law or Stay of Prosecution shall be allowed or admitted.

Robt. Daniell (seal)
Tho. Smith ..
Char. Hart ..
Geo. Logan ..
Nich. Trott ..
Saml. Eveleigh ..

Read three times and ratified
in open Assembly.
June the 30th, 1716

DETERMINATION OF PRESERVATIVE PENETRATION

The most important single criterion of the thoroughness of treatment is the depth of penetration of the preservative, which is relatively simple to determine and may be measured at any time after the timber has been impregnated. Penetration can be measured most accurately on cross sections of wood, sawed out of timbers and then split into several pieces for inspection, but this procedure generally destroys the utility of the treated sticks. Consequently, it is the usual practice to extract small cores from the impregnated timbers by means of an increment borer, making the borings at right angles to the sides of the sticks; the resulting holes should be tightly filled with thoroughly treated wooden plugs, in order to maintain the protective shell of treated wood. Bit holes bored into the treated timbers will serve the same general purpose, although not so effectively. Several borings will provide a better estimate of the average depth of penetration in a given timber than a single sample, but it is the usual practice to bore only one hole in each stick that is to be inspected.

The cross sections or borings should be taken at some distance from the ends of the timbers, in order to avoid sampling the unrepresentative parts which are completely treated by end penetration. The safest place to determine penetration is the mid-length of the timber or of the treated area. Failure to observe this precaution has deceived many an inexperienced investigator into believing that his preservative or his treating method gives complete penetration of the wood. This difficulty is often encountered when the experimental apparatus employed for impregnating the wood necessitates the use of such short test specimens that complete penetration of the sticks is easily obtained from the end surfaces.

CREOSOTED WOOD

When wood has been impregnated with creosote (or any other distinctly colored preservative), penetration can be readily determined by direct observation of the cross sections or cores. The saw or increment borer may carry some creosote over the untreated surface of a sample and thus make the depth of penetration appear greater than it actually is. This difficulty may be obviated by splitting the sample and observing the penetration on the split surface; in the case of a boring, the core should be split in half for its full length. In any event, inspection should be made at once, since the creosote will gradually creep over the untreated surface of the sample.

ZINC-CHLORIDE-TREATED WOOD

Since zinc chloride solution is colorless, its depth of penetration in wood cannot be observed directly, and it is necessary to use a chemical spray or dip which will set up a definite color distinction between the treated and untreated surfaces of the cores or cross sections taken from the impregnated timbers. The color test in general use today is the following "American Wood-Preservers' Association Standard Method for Determining Zinc Chloride Penetration by Color Reaction Test with Iodine-Potassium Ferricyanide-Starch":

Chemical Principle.—The iodine method for determining zinc chloride penetration is based on the principle that zinc ferricyanide liberates free iodine and free iodine in turn gives a dark blue stain with starch solution. It is evident then that the zinc chloride that has been injected into the ties will react with potassium ferricyanide, making zinc ferricyanide, and this in turn will liberate free iodine and give the blue stain as stated above. It is a well-known fact that free iodine can be detected in very minute quantities with starch solution, and can be made a very delicate test, such as detecting minute amounts of zinc chloride in treated ties.

Preparation of Solutions.—Prepare about 200 cc. each of the following stock solutions, to be kept separate until used:

1% solution of potassium ferricyanide.

1% solution of potassium iodide.

5% solution of soluble starch.

In making a starch solution, be sure to boil until the starch is in solution, otherwise the reaction will not be satisfactory. A starch solution will not keep long, and must not be used when it begins to sour. Be sure the starch solution is reasonably fresh.

Method of Application.—The disk of wood to be tested should be reasonably dry. Mix 10 cc. each of the 3 stock solutions, and pour into a good atomizer. A De Vilbiss No. 30 has been found satisfactory. Spray the disk of wood evenly all over. The reaction between the zinc chloride and the spraying solution will instantly cause the treated wood to turn a deep blue, while the untreated part will retain its original color. This method is a positive test. Should the color fade, repeat the process.

"Soluble starch" is not the ordinary laundry product but a specially prepared starch which may be purchased from practically any chemical supply house. The starch solution used in the foregoing test may be prepared by placing 50 g. of "soluble starch" in a 200-cc. beaker, stirring it in enough cold water to make a thin, uniform paste, and then pouring this into enough hot water to make a total volume of 1000 cc. The mixture should be kept well stirred, and boiled for a few minutes until nearly clear. In order to preserve the starch solution, 10 cc. of a 10 per cent solution of potassium iodide saturated with mercury iodide should be added.

DETERMINATION OF SAPWOOD DEPTH

Specifications often require that the penetration be not less than a percentage of the sapwood depth. In such cases, it is necessary to determine the dividing line between heartwood and sapwood. If the color contrast between the two parts of the wood is sharp, the line will be readily apparent to the eye. In many woods, however, the color of the heartwood and sapwood is so nearly the same that there is no clear-cut distinction between them. In such cases, the following nigrosine dye test is often helpful in making the determination:

A shallow container is filled brimful with a 1 per cent solution of nigrosine (a black water-soluble dye). A boring, taken from the wood and preferably split, is then held by the outer edge with the end grain of the wood downward, and dragged slowly across the edge of the container so that the dye solution just touches the lower edge of the boring. The dye penetrates upward quickly in untreated sapwood and slowly in untreated heartwood, and the dividing line between the two parts of the wood can usually be determined by the difference in rate of absorption of the dye. If all the sapwood is penetrated with creosote, or if the creosote has penetrated into the heartwood, this test does not show the dividing line clearly. The test is not infallible, even with untreated wood, but it is the best yet developed and is in rather common use. While nigrosine is the preferred test dye, any other water-soluble dye or colored solution that is readily absorbed by sapwood and not by heartwood should give similar results.

SAMPLE SPECIFICATION FOR PRESERVATIVE TREATMENT OF TIMBER

The following "Standard Specification for the Preservative Treatment of Southern-pine Poles by Pressure Processes," listed as No. 36*c* in the American Wood-Preservers' Association Manual of Recommended Practice, is included for the purpose of illustrating the character and details of such a statement of particulars:

1. GENERAL REQUIREMENTS.

1.1. The following requirements (1.2 to 1.5 and 3. to 6.4 inclusive) apply to each of the treatment processes. If these requirements are to be modified to meet special conditions, complete detailed instructions shall be given.

1.2. Plant Equipment.—Treating plants shall be equipped with the thermometers and gauges necessary to indicate and record accurately the conditions at all stages of treatment, and all equipment shall be maintained in acceptable, proper working condition. The apparatus and chemicals necessary for making the analyses and tests required by the purchaser shall also be provided by plant operators, and kept in condition for use at all times.

1.3. Conditioning.—Poles shall be conditioned by air-seasoning or by steaming or by a combination of both as agreed upon, in such a manner as will not cause injurious checking, splitting or warping.

1.31. When air-seasoning is used the poles shall be treated before they begin to decay.

1.32. When steam conditioning is used poles shall be steamed in the cylinder at temperatures between 254 deg., F., and 259 deg., F. (approximately 20 lb. pressure per sq. in.) for not less than 6 hr. and not more than 15 hr., which temperature maximum shall not be reached in less than 1 hr. The cylinder shall be provided with vents to relieve it of air and insure proper distribution of steam. After steaming is completed, a minimum vacuum of 24 in. at sea level shall be maintained for not less than 1 hr. The cylinder shall be relieved continuously or frequently enough to prevent condensate from accumulating in sufficient quantity to reach the wood. Before the preservative is introduced the cylinder shall be drained of condensate.

1.4. Sorting.—Whenever it is practicable, poles should be sorted into size and seasoning groups, and the treatment of large and small pieces or green and seasoned pieces in the same charge should be avoided.

1.5. Framing.—So far as practicable all surfacing, framing, and boring shall be done prior to treatment; but gaining and boring bolt holes and step holes shall be permitted after treatment on poles with 100 per cent sapwood penetration, provided the surfaces of such gains and holes are painted or swabbed with hot preservative.

2. TREATMENT.

2.1. Oil Treatment.

2.11. Manner of Treatment.—Following the conditioning period, the poles shall be treated by an empty-cell process whenever practicable, in order to obtain as deep and uniform penetration as possible with the retention of preservative stipulated. Poles shall be treated by the full-cell process only when the maximum net retention is desired and where pressure is held to refusal, or when the stipulated retention is greater than can be obtained by the use of an empty-cell process. The ranges of pressure, temperature and time duration shall be controlled so as to get the maximum penetration by the quantity of preservative injected.

Standard Processes

Empty-cell

Rueping

2.11111. Poles shall be subjected to initial air pressure of the necessary intensity and duration. The preservative shall be introduced until the cylinder is filled, the air pressure being maintained constant during the filling operation. The pressure shall be raised to not more than 200 lb. per sq. in. Poles shall be held under pressure until there is obtained the largest practicable volumetric injection that can be reduced to the stipulated retention by ejection of surplus preservative from expansion of the air initially introduced and by a quick high vacuum.

2.11112. The temperature of the preservative immediately after the cylinder is filled and during the entire pressure period shall be not more than 210 deg., F., and shall average at least 180 deg., F.

2.11113. After pressure is completed the cylinder shall be emptied speedily of preservative, and a vacuum of not less than 22 in. at sea level created promptly and maintained until the wood can be removed from the cylinder free of dripping preservative.

Lowry

2.11121. The preservative shall be introduced until the cylinder is filled, the atmospheric pressure being maintained during the filling operation. The pressure shall be raised to not more than 200 lb. per sq. in. Poles shall be held under pressure until there is obtained the largest practicable volumetric injection that can be reduced to the stipulated retention by ejection of surplus preservative from expansion of the air and by a quick high vacuum.

2.11122. The temperature of the preservative immediately after the cylinder is filled and during the entire pressure period shall be not more than 210 deg., F., and shall average at least 180 deg., F.

2.11123. After pressure is completed, the cylinder shall be emptied speedily of preservative, and a vacuum of not less than 22 in. at sea level created promptly and maintained until the wood can be removed from the cylinder free of dripping preservative.

Full-cell

Bethell

2.11211. Poles shall be subjected to a vacuum of not less than 22 in. at sea level for not less than 30 min. The preservative shall be introduced until the cylinder is filled without first breaking the vacuum. The pressure shall be raised to not more than 200 lb. per sq. in. Poles shall be held under pressure until there is obtained the volumetric injection that will insure the stipulated retention, or until the wood is treated to refusal.

2.11212. The temperature of the preservative immediately after the cylinder is filled and during the entire pressure period shall be not more than 210 deg., F., and shall average at least 180 deg., F.

2.11213. After pressure is completed the cylinder shall be emptied speedily of preservative, and a vacuum of not less than 22 in. at sea level created promptly and maintained until the wood can be removed from the cylinder free of dripping preservative.

3. RESULTS OF TREATMENT.

3.1. Retention of Preservative.—The net retention in any charge shall be not less than 95 per cent of the quantity of preservative that may be specified; but the average retention by the poles treated under any contract or order and the average retention of any five consecutive charges shall be at least 100 per cent of the quantity specified. The amount of preservative retained shall be calculated from readings of working tank gauges, or scales, or from weights before and after treatment of loaded trams on suitable track scales.

3.11. The volume of preservative shall be calculated on the basis of 100 deg., F. Calculations of volume or weight shall be made by the use of temperature or specific gravity factors contained in the Volume and Specific Gravity Correction tables of the American Wood-Preservers' Association.

3.2. The amount of preservative retained shall be as follows, depending on use requirements, and as stipulated in purchaser's order and in accordance with Section 3.1:

3.21. 8 lb. of creosote per cu. ft. of wood in charge, or

3.22. 10 lb. of creosote per cu. ft. of wood in charge, or

3.23. 12 lb. of creosote per cu. ft. of wood in charge.

3.3. Penetration.—The penetration desired shall be specified by the purchaser in accordance with use requirements. Not less than the following penetrations should be specified for 8-lb., 10-lb., and 12-lb. retentions.

3.31. The penetration in any pole treated to an 8-lb. retention shall be not less than 2.5 in. unless 85 per cent of the sapwood is penetrated.

3.32. The penetration in any pole treated to a 10-lb. retention shall be not less than 3 in. unless 90 per cent of the sapwood is penetrated.

3.33. The penetration in any pole treated to a 12-lb. retention shall be not less than 3.5 in. unless 90 per cent of the sapwood is penetrated.

3.4. Determination of Penetration.—The number of poles to be bored in each charge and the tolerance to be allowed in accepting poles treated under this specification shall be in accordance with paragraphs 3.42, 3.421, and 3.422, unless otherwise specified by the purchaser.

To facilitate inspection for conformance to the penetration requirements poles may be divided into the classes and lengths shown in the following table.

Class	1	2	3	4	5	6	7	8	9	10
Minimum top circumference, inches	27	25	23	21	19	17	15	18	15	12
Length of pole, feet	Minimum circumference at six feet from butt, inches									
16	....	....	....	....	21.5	19.5	18.0			
18	....	....	26.5	24.5	22.5	21.0	19.0	No butt requirement		
20	31.5	29.5	27.5	25.5	23.5	22.0	20.0			
22	33.0	31.0	29.0	26.5	24.5	23.0	21.0			
25	34.5	32.5	30.0	28.0	26.0	24.0	22.0			
30	37.5	35.0	32.5	30.0	28.0	26.0	24.0			
35	40.0	37.5	35.0	32.0	30.0	27.5	25.5			
40	42.0	39.5	37.0	34.0	31.5	29.0	27.0			
45	44.0	41.5	38.5	36.0	33.0	30.5	28.5			
50	46.0	43.0	40.0	37.5	34.5	32.0	29.5			
55	47.5	44.5	41.5	39.0	36.0	33.5				
60	49.5	46.0	43.0	40.0	37.0	34.5				
65	51.0	47.5	44.5	41.5	38.5					
70	52.5	49.0	46.0	42.5	39.5					
75	54.0	50.5	47.0	44.0						
80	55.0	51.5	48.5	45.0						
85	56.5	53.0	49.5							
90	57.5	54.0	50.5							

3.41. Grouping Poles for Penetration Inspection.—Poles may be divided for inspection for the penetration requirements into two groups, *viz.:*

Group A.—Small poles, of the following classes and lengths:

Class 1, 25 ft. and shorter
Class 2, 30 ft. and shorter
Class 3, 35 ft. and shorter
Class 4, 45 ft. and shorter
Class 5, 55 ft. and shorter
Classes 6 to 10, all lengths

This group includes all guy stubs, reinforcing stubs and push braces.

Group B.—Large poles, including all classes and lengths not in Group A.

3.42. Methods of Inspection for Penetration.—The following methods of inspection shall be considered as minimum routine for determining conformity to the penetration requirements:

3.421. Poles in Group A.—An increment borer core shall be taken approximately midway between the butt and top of each of 20 poles in each charge.

3.4211. If 18 of the 20 borings meet the penetration requirements, the charge as a whole shall be considered as conforming.

3.4212. If 16 or 17 of the 20 borings meet the penetration requirements, each pole in the charge shall be bored as previously indicated and only those poles that meet the penetration requirements shall be considered as conforming.

3.4213. If less than 16 of the 20 borings meet the penetration requirements, the charge as a whole shall be considered as nonconforming.

3.422. Poles in Group B.—An increment borer core shall be taken approximately midway between the butt and top of all poles in Group B, and only those poles that meet the penetration requirements shall be considered as conforming.

Note: If the poles are not handled on the class and length basis shown in the table, an approximately comparable division may be made by listing all poles with circumferences at 6 ft. from the butt less than 37.5 inches as Group A poles, and all poles with circumferences at 6 ft. from the butt of 37.5 inches or more as Group B poles.

3.423. Plugging Penetrance Test Holes.—All holes for determining penetration shall be plugged tightly with creosoted plugs or with untreated plugs of durable heartwood approved by the purchaser.

4. PRESERVATIVES.

The preservative used shall conform to the American Wood-Preservers' Association Standard 4—Standard Specification for Creosote.

5. INSPECTION.

Inspection of poles for conformity to the requirements of this specification shall be in accordance with American Wood-Preservers' Association Standard 33, amplified by Section 3.4 above

6. RETREATMENT.

Poles not conforming to the stipulated minimum requirements may be retreated and may be reoffered for acceptance but retreatment should be avoided so far as practicable. If retreatment is necessary it shall be under the following conditions:

6.1. The maximum limits for temperature of steam or preservative and the maximum limit for preservative pressure, that apply to original treatments, shall not be exceeded during retreatment.

6.2. When a charge to be retreated is made up entirely of black nonconforming or rejected poles, the amount of preservative retained in the retreatment shall be at the discretion of the creosoter, provided the total net retention does not fall below the minimum requirements.

6.3. When it is necessary to retreat black poles in the same charge with white untreated poles, the number of black poles in the charge shall not exceed 5 per cent of the total poles in the charge.

6.4. In the computation of the required minimum net retention in any charge containing both black and white poles, all poles in the charge shall be considered as untreated.

Revised, 1937.

STATISTICAL DATA

Table XXV.—Comparative Statement of Material Treated in the United States, 1909–1936*

Preservative	Year	Crossties	Switch ties†	Piles	Poles‡	Wood blocks	Cross-arms	Const. timbers	Misc. material	Total
		Cubic feet								
Creosote	1909	29,830,080	...	4,421,726	659,664	2,994,290	41,764	4,902,311	417,787	43,267,622
	1910	44,525,229	...	5,219,254	255,597	4,692,453	88,069	7,801,272	2,687,713	65,269,587
	1911	49,532,163	...	4,937,363	106,213	10,145,724	71,961	7,417,105	2,499,995	74,710,524
	1912	57,461,515	...	7,624,939	1,169,981	7,091,658	1,643,128	6,892,493	2,841,195	84,724,909
	1913	75,998,307	...	7,630,328	2,367,769	6,810,308	1,813,010	10,308,883	1,853,993	106,782,598
	1914	67,774,329	...	7,804,657	1,188,511	3,127,506	395,403	8,389,158	1,348,566	90,028,130
	1915	51,231,207	...	6,288,238	2,336,318	6,064,758	87,373	9,264,164	881,028	76,153,086
	1916	62,576,403	...	8,524,680	6,303,954	7,205,953	178,210	9,521,609	691,870	95,002,679
	1917	48,685,554	...	8,493,715	5,930,559	4,610,427	239,764	7,830,673	706,084	76,496,776
	1918	34,638,147	...	7,620,974	4,540,620	4,825,766	210,903	7,606,153	707,294	60,149,857
	1919	44,938,215	...	9,151,972	6,649,491	3,372,828	75,310	9,220,880	553,750	73,962,446
	1920	40,114,551	...	8,013,192	10,309,746	6,741,410	318,707	9,054,413	1,139,307	75,691,326
	1921	66,139,398	...	5,528,275	10,906,157	6,202,904	108,715	9,052,679	663,183	98,601,311
	1922	60,625,086	...	7,494,649	16,482,963	3,947,551	374,829	10,632,378	1,029,509	100,586,965
	1923	104,167,710	...	9,569,443	26,235,810	4,464,277	420,206	16,484,703	2,720,457	164,062,606
	1924	103,781,958	...	11,680,941	36,716,768	2,930,639	517,811	19,571,314	2,777,891	177,977,322
	1925	107,465,910	10,802,429	9,594,891	42,178,365	2,592,471	621,705	13,187,277	2,562,988	189,006,036
	1926	114,699,741	9,635,644	12,314,762	49,511,088	3,072,838	1,338,099	15,433,400	2,509,141	208,514,713
	1927	131,441,691	10,519,261	11,623,823	63,884,656	145,338	1,008,192	16,066,019	7,388,187	242,077,167
	1928	116,937,954	10,633,809	13,599,253	63,423,271	577,883	1,205,604	17,507,180	6,384,237	230,269,191
	1929	126,559,344	10,263,481	16,949,537	74,415,405	6,750,177	1,877,338	17,320,035	8,733,903	262,869,220
	1930	117,179,841	10,685,378	16,570,876	70,498,226	5,002,733	1,115,944	16,646,617	7,977,750	245,677,365
	1931	91,670,097	8,321,782	11,883,240	38,502,869	1,246,854	304,041	13,857,179	5,137,217	170,923,279
	1932	65,748,954	6,223,898	6,644,409	21,545,304	473,652	286,100	8,478,164	3,453,027	112,853,508
	1933	36,804,687	4,590,619	5,898,715	29,679,602	349,897	201,380	10,155,411	2,282,864	89,963,175
	1934	53,672,457	4,863,023	8,566,829	31,582,568	831,012	141,642	11,716,740	4,227,844	115,602,115
	1935	60,164,043	4,818,578	8,110,477	35,337,597	1,483,810	351,367	12,864,930	4,599,202	127,730,004
	1936	64,731,900	6,429,164	12,443,018	53,840,160	2,115,243	532,876	15,752,648	5,560,118	161,405,127
Creosote-petroleum §	1924	22,292,520	...	...	...	...	...	1,834,141	170,548	24,297,209
	1925	27,688,797	1,102,914	41,856	19,818	2,691	...	452,773	135,350	29,444,199
	1926	28,129,140	2,149,398	43,728	...	...	6,307	1,605,562	185,460	32,119,595
	1927	47,373,441	3,023,531	11,833	131,173	...	...	824,242	368,049	51,732,269
	1928	53,157,537	2,367,658	66,141	187,176	131,741	1,908	2,140,589	244,891	58,297,641
	1929	55,547,214	3,195,614	170,427	183,234	75,057	12,627	2,271,515	369,262	61,824,950
	1930	49,076,679	2,784,609	421,769	167,042	4,977	1,800	1,472,745	485,449	54,415,070
	1931	36,611,991	1,725,526	142,925	8,659	...	610	1,952,149	272,117	40,713,977
	1932	25,126,419	1,694,996	150,095	...	...	12	1,049,860	66,672	28,088,054

	1933	22,405,005	707,738	278,897	119,416	38,640	4,593	1,112,397	95,293	24,761,979
	1934	26,663,808	1,765,351	50,865	9,962	578		2,769,360	83,530	31,343,454
	1935	36,760,266	2,744,975	448,676	29,920			1,405,727	146,270	41,535,834
	1936	44,545,935	1,642,259	386,426	107,923			2,546,917	143,905	49,373,365
Zinc-creosote	1909	8,095,794						62,918	43,699	8,202,411
	1910	6,354,219		38,392				181,143	30,646	6,604,400
	1911	7,312,374								7,312,374
	1912	8,214,303		97,874				560,613	99,367	8,972,157
	1913	6,938,838		327,594				758,989	53,628	8,079,049
	1914	5,868,834						140,718		6,009,552
	1915	6,548,136		2,320	110,220			40,396	4,822	6,705,894
	1916	5,935,242		837	53,933			359,428		6,349,440
	1917	6,482,046						1,102,635	847	7,585,528
	1918	6,023,334		167,438	12,300	76,393	209,927	164,813	125,327	6,779,532
	1919	8,850,222		14,059				562,403	58,399	9,485,083
	1920	7,414,866		79,354				484,123	5,231	7,983,574
	1921	9,183,702		61,386				48,237	2,499	9,295,824
	1922	11,045,913		111				684,242	14,176	11,744,442
	1923	10,507,173						403,531	35,525	10,946,229
	1924	15,716,883						898,679	70,723	16,686,285
	1925	12,180,018	458,999					641,484	158,591	13,439,092
	1926	9,385,131	247,780					752,930	81,206	10,467,047
	1927	11,150,988	622,722	24,666					117,666	11,916,042
	1928	8,607,213	346,201					111,230	30,947	9,095,591
	1929	4,884,891	260,759					150,611	32,009	5,328,270
	1930	4,034,838	296,481						54,312	4,385,631
	1931	5,065,050	364,812					13,766	5,487	5,449,115
	1932	3,346,128	67,540						6,570	3,420,238
	1933	2,125,659	54,540					291	598	2,181,088
Zinc chloride	1909	24,153,162						320,891	2,333	24,476,386
	1910	27,587,583						541,514	71 060	28,200,157
	1911	28,337,883						1,043,851	119,931	29,501,665
	1912	28,532,874			18,246			259,972	20,092	28,831,184
	1913	36,051,816			47,996			585,756	7,670	36,693,238
	1914	50,020,755						1,317,925	4,355	51,343,035
	1915	53,457,852		4,726				2,406,150	275,279	56,144,007
	1916	43,859,028		859	164			1,526,881	346,047	45,732,979
	1917	44,529,954		7,093	45,788	10,421		2,127,872	5,070	46,726,198
	1918	51,166,146		57,845		13,939		2,337,169	30,790	53,605,889
	1919	58,912,323		2,919				2,164,007	63,987	61,143,236
	1920	87,398,160						1,823,437	94,151	89,315,748
	1921	90,797,841		298				2,738,292	67,835	93,604,266
	1922	52,254,303		2,029				1,296,980	19,564	53,572,876
	1923	46,138,005						1,948,562	26,872	48,113,439
	1924	46,033,341						1,858,685	85,537	47,977,563

TABLE XXV.—COMPARATIVE STATEMENT OF MATERIAL TREATED IN THE UNITED STATES, 1909–1936*—(*Continued*)

Preservative	Year	Crossties	Switch ties†	Piles	Poles‡	Wood blocks	Cross-arms	Const. timbers	Misc. material	Total
		Cubic feet								
Zinc chloride‖	1925	40,150,287	1,252,418	....	....	....	....	84,151	47,815	41,534,671
	1926	35,480,577	1,144,564	62,487	....	....	....	172,806	155,551	37,015,985
	1927	32,639,400	1,035,420	....	....	....	....	262,092	315,908	34,252,820
	1928	31,475,508	1,185,512	....	1,056	....	....	134,738	410,042	33,206,856
	1929	25,836,828	698,903	....	94,459	....	....	34,736	860,033	27,524,959
	1930	19,278,987	854,415	....	....	....	....	93,758	912,405	21,139,565
	1931	12,440,646	451,824	....	....	9,713	....	132,161	428,186	13,462,530
	1932	9,499,317	617,438	....	2,112	....	84,569	110,087	136,732	10,450,255
	1933	5,931,387	53,470	....	....	....	107,282	422,250	443,218	6,957,607
	1934	4,233,207	149,021	3,843	....	....	....	129,310	725,938	5,241,319
	1935	6,254,922	271,815	....	3,397	....	....	236,349	482,236	7,248,719
	1936	3,660,045	525,464	1,006	107,237	....	....	896,202	902,511	6,092,465
Miscellaneous	1912	2,974,317	....	14,222	352	305,437	....	80,446	28,032	3,402,806
	1913	1,792,287	....	....	84,655	45,185	11,709	....	124,367	2,058,203
	1914	7,877,043	....	257,245	293,896	3,741,864	22,511	....	9,363	12,201,922
	1915	19,560	....	....	66,242	1,643,213	3,254	123,377	330	1,855,976
	1916	37,431	....	56,458	389,031	2,738,731	2,634	166,183	47,416	3,437,884
	1917	680,856	....	85,204	749,156	4,464,382	16,274	433,896	100,316	6,530,084
	1918	....	....	463,115	62,850	1,381,196	2,541	107,458	60,452	2,077,612
	1919	3,021	....	....	11,775	1,340,850	....	114,583	....	1,470,229
	1920	35,019	....	....	....	....	....	283,838	....	318,857
	1921	29,604	....	2,040	53,099	....	....	37,500	19,584	141,827
	1922	24,120	....	....	525,677	....	....	99,480	66,787	716,064
	1923	17,637	....	....	651,094	468,030	....	999	115,434	1,253,194
	1924	73,428	....	4,815	....	1,260,921	....	128,412	177,280	1,644,856
	1925	206,721	....	....	6,230	813,327	....	10,008	14,255	1,050,541
	1926	269,025	....	....	....	616,586	....	5,203	313,925	1,204,739
	1927	90,000	....	....	12,778	5,126,082	....	191,709	286,937	5,707,506
	1928	165,003	270	....	714,473	2,966,688	....	264,010	940,656	5,051,100
	1929	241,032	6,885	6,830	2,461,219	26,896	67,466	426,914	1,224,406	4,461,648
	1930	230,976	1,830	34,508	4,592,878	4,735	181,502	800,249	854,268	6,700,946
	1931	45,708	33,588	93,715	1,454,534	....	14,974	668,817	474,065	2,785,401
	1932	1,415,631	....	21,028	399,784	16,532	223	482,471	270,865	2,606,534
	1933	822,957	23,911	26,001	321,816	....	185	466,403	430,706	2,091,979
	1934	809,289	1,099	17,137	477,910	211,312	377,346	670,074	354,668	2,918,835
	1935	330,210	1,120	15,389	422,206	....	109	1,176,300	979,079	2,924,413
	1936	918,507	5,558	99,918	843,445	....	71,171	1,235,204	2,419,234	5,593,037

All preservatives	1909	62,079,036		4,421,726	659.664	2,994,290	41 764	5,286.120	463,819	75,946,419
	1910	78,467.031		5,257,646	255,597	4,692,453	88,069	8,523,929	2,789,419	100,074,144
	1911	85,182,420		4,937,363	106.213	10 145,724	71,961	8,460,956	2,619,926	111,524,563
	1912	97,183,009		7,737,035	1,188,579	7,397,095	1,643.128	7,793,524	2,988,686	125,931,056
	1913	120,781.248		7,957,922	2,500,420	6,855,493	1,824,719	11,653,628	2,039,658	153,613,088
	1914	131,540,961		8,061 902	1,482,407	6,869 370	417.914	9,847,801	1,362,284	159,582,639
	1915	111,256,755		6,295,284	2.512,780	7,707 971	90,627	11,834,087	1,161 459	140,858,963
	1916	112.408.104		8,582,834	6.747,082	9,944.684	180,844	11.574 101	1,085,333	150,522,982
	1917	100,378,410		8,586,012	6,725,503	9.085,230	256,038	11.495 076	812,317	137,338.586
	1918	91,827,627		8,309,372	4,615,770	6,297,294	423,371	10,215,593	923.863	122,612,890
	1919	112,703 781		9,168,950	6,661,266	4,713,678	75,310	12 061,873	676,136	146,060.994
	1920	134.952,596		8.092,546	10,309,746	6,741,410	318,707	11,645,811	1,238,689	173,309,505
	1921	166,150,545		5,591,999	10,959,256	6.202,904	108,715	11,876.708	753,101	201,643,228
	1922	123,949.422		7,496,789	17,008,640	3,947,551	374.829	12.713,080	1.130,036	166,620.347
	1923	160,830.525		9.569,443	26,886,904	4.932,307	420,206	18 837,795	2,898,288	224,375,468
	1924	187,898 130		11,685,756	36,716.768	4,191,560	517,811	24.291,231	3,281,979	268,583,235
	1925	187.691,733	13,616,760	9,636,747	42.204,413	3,408.489	621,705	14,375,693	2.918,999	274,474 539
	1926	187,963,614	13,177,386	12,420.977	49,511,088	3,689,424	1,344,406	17,969,901	3,245,283	289,322,079
	1927	222,695,520	15,200,934	11,660,322	64,028,607	5,271,420	1,008,192	17,344,062	8,476,747	345,685,804
	1928	210,343 215	14,533.450	13.665,394	64,325,976	3,676,312	1,207,512	20,157.747	8,010.773	335,920,379
	1929	213,069,309	14,425.642	17.126,794	77,154,317	6.852,130	1,957,431	20.203,811	11.219,613	362,009,047
	1930	189,801.321	14.622,713	17,027,153	75,258,146	5,012,445	1,299,246	19,013,369	10.284,184	332,318,577
	1931	145,833.492	10,897,532	12,119.880	39,966 062	1 256,567	319,625	16,624,072	6.317,072	233,334,302
	1932	105,136,449	8,603.872	6,815 532	21.947,200	490,184	370,904	10,120,582	3,933,866	157,418,589
	1933	68,089,695	5,430,278	6.203,613	30.120,834	388,537	313.440	12,156,752	3.252,679	125,955,828
	1934	85,378.761	6.778,494	8,638 674	32 070,440	1,042,902	518.988	15.285.484	5,391.980	155,105,723
	1935	103,509,441	7,836,488	8.574,542	35,793,120	1,483 810	351,476	15.683,306	6.206,787	179,438,970
	1936	113.856,387	8,602,445	12,930,368	54,898.765	2,115,243	604,047	20.430,971	9,025,768	222,463,994

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* From Helphenstine, R. K., Jr.: Quantity of wood treated and preservatives used in the United States in 1936. *Proc. 33d Ann Meeting. Am. Wood-Preservers' Assoc.* (1937).

† Included in construction timbers prior to 1925. ‡ Includes both full length pressure treated poles and nonpressure (butt-treated) poles.

§ Not shown for years prior to 1924. ‖ Includes chromated zinc chloride in 1936.

Converting Factors:

To obtain the number of crossties treated, divide figures shown by 3
To obtain the number of board feet of switch ties, multiply the figures shown by 12.
To obtain the number of linear feet of piles treated, divide the figures shown by 0 6763
To obtain the number of square yards of wood blocks, divide the figures shown by 2.625.
To obtain the number of board feet of construction timbers, multiply the figures shown by 12
To obtain the number of board feet of miscellaneous material multiply the figures shown by 12
To obtain the number of poles, divide the figures shown by 17.6
To obtain the number of crossarms divide the figures shown by 0.6198.

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